PERFORMANCE STUDY OF SPRAY DRYER USING VARIOUS SALT SOLUTIONS

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BY

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CERTIFICATE

This is to certify that the work in this thesis report "Performance Studies of Spray Dryer using various Salt Solution" by Ms. Arati Parihari, has been carried out under our guidance in partial fulfillment of the requirement for the degree of Master of Technology (Res.) in Chemical Engineering session 2006-2008 in the department of Chemical engineering, National Institute of Technology Rourkela and this work has not been submitted elsewhere for a degree.

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SYNOPSIS

Introduction:

Spray drying is an essential unit operation for the manufacture of many products with specific powder properties. It is characterized by atomization of a solution or suspension into droplets, followed by subsequent drying of these droplets by evaporation of water or other solvents. Spray drying is used for the manufacture of many consumer and industrial products such as instant food products, laundry detergents, and pharmaceuticals. It is well suited to continuous production of dry solids in powder, granulate or agglomerate particle form from liquid feed-stocks.

Spray drying starts with the atomization of a liquid feedstock into a spray of droplets. Next, the droplets are put in contact with hot air in a drying chamber. The sprays are produced by either rotary (wheel) or nozzle atomizers of different types. Evaporation of moisture from the droplets and formation of dry particles proceed under controlled temperature and airflow conditions. Powder is continuously discharged from the drying chamber and recovered from the exhaust gases using a cyclone or a bag filter. The whole process generally takes no more than a few seconds. Correct atomization and air distribution are the keys to the spray drying process, as both greatly influence the final powder structure and quality. Often, spray dryers are equipped with high-speed centrifugal atomizers ensuring sturdy and reliable operation. High-Pressure nozzle atomization is used especially for products where a rather coarse powder with narrow particle distribution and high bulk density is required. In the nozzle atomizer, fines are returned around one or more central nozzles in order to facilitate optimum agglomeration. Two-Fluid nozzle agglomeration is typically applied in small chambers allowing maximum flexibility in particle design and particle engineering for both super-fine and agglomerated particles.

Some advantages of spray drying include the ability to produce a dry powder rapidly and the ability to control the particle size distribution. The limitations of spray drying include problems with efficient particle collection and the potential instability of materials sensitive to high temperatures.

The primary goal of spray drying is removing water. Under normal operating conditions the powder particles are enough dry before they hit the walls of the spray dryer, such that they do not stick to the walls. The drying behavior strongly depends on the spray characteristics and the feed composition. Stickiness is related to the drying state of the particles. Incorrect operating conditions, which do not match the drying behavior of the particles, can therefore lead to fouling.

The objective of this study is to examine the effects of process variables on particle size and other characteristics of various spray-dried salt solutions. Using a lab-scale apparatus, the effects of various spray-drying process parameters on the product have been examined. Predicting these parameters' effect on particle characteristics will be useful in future development of spray-dried products.

The work undertaken has been presented in five chapters and two appendices in the thesis.

Chapter-1 outlines the introduction to spray drying process, ranges, its application in various industries, advantages, limitations and the plan of the present work.

Chapter-2 presents the literature review of different types of spray dryers, unit operations used in spray drying process, pre-concentration of liquid feed, limitations on pre-concentration, atomization and different types of atomization, heat and mass transfer in the dryer, drying of a droplet, separation of dry particles, applications, structure of spray dried powder particles, dispersion characteristics of spray dried powders, instantized powders , particle agglomeration after instantizing process, selection of operating conditions, factorial design and fractional factorial design, artificial neural network method for calculating outlet and ANN- data processing procedure.

Chapter-3 describes the experimental set-up, specification of different parts and experimental procedure. Altogether 45 sets of run have been taken. The independent system variables include inlet temperature, aspirator speed, inlet feed pump flow rate, atomization rate, concentration of salt solutions molecular weight of salts and dependant variables are outlet temperature and percentage yield. Varying one independent parameter at a time and keeping other parameters constant, the variation of the dependant variable has been studied. Two major sets of data collected, one is for various salt solutios and the other is for blank solution (water).For water only four parameters are considered, these are inlet temperature, aspirator speed, inlet pump flow rate and atomization rate. This chapter also presents the data analysis for the development of correlations among various system parameters in the dimensional approach method, the FTIR,TGA and SEM report of the spray dried particles.

Chapter-4 deals with the prediction of outlet temperature and percentage yield of various salt solutions. The outlet temperature and the percentage being the function of various system parameters can be expressed as a function of the parameters. The analysis of the experimental data for the effect of individual system parameters has been carried out. Using the values of the constants and the exponents as obtained by the regression analysis of the data, the final correlation for the outlet temperature and the percentage yield have been obtained as below:

1. **Outlet temperature for salt solution**

$$T_o = 2.2032\left[(T_1)^{0.079}(U_{asp})^{0.2026}(U_p)^{-0.229}(C_s)^{-0.0653}(P_{i-air})^{-0.1567}(M_s)^{0.1259}\right]$$

2. **Percentage yield of salt solution**

$$Y = 251.09\left[(T_i)^{-0.1532}(U_{asp})^{-0.0913}(U_p)^{-0.6651}(C_s)^{0.0659}(P_{i-air})^{-0.2518}(M_s)^{-0.0375}\right]$$

3. Outlet temperature of water

$$T'_o = 10.874\left[(T_1)^{0.609}\left(U_{asp}\right)^{0.1404}\left(U_p\right)^{-0.4364}\left(P_{i-ait}\right)^{-0.1748}\right]$$

The calculated values of the outlet temperature and percentage yield through the model have been compared with the experimental values. It is found that the percentage deviation varies between ± 5%.This chapter includes the discussion of the effect of variation of various system parameters on the physical characteristics of the products obtained from the spray dryer.This chapter also includes the development of correlation using factorial design and fractional factorial design method,correlation are given below.It also includes the ANN-analysis of the observed experimental data and comparison of the outlet parameter with the experimental values by three methods, the moisture analysis, morphological behavior of the particles from the SEM report and the analysis of the FTIR and TGA report of the spray dried particles.

4. For salts the equations are

$$T_O = 51.96 + (-1.294)A + (-0.406)B + (-2.98)C + (-1.56)D + (2.606)E + (-1.45)F + (0.194)AB + (-2.73)AC + (-3.18)AD + (-1.84)BC + (0.256)BD + (3.58)CD + (2.08)ABD + (0.76)ACD + (0.72)ABCD$$

5.

$$Y = 62305 + (-4.34)A + (5.14)B + (-2.08)C + (-2.99)D + (1.31)E + (-0.345)F + (-0.395)AB + (-2.56)AC + (-2.27)AD + (2.67)BC + (2.07)BD + (-1.28)CD + (-0.67)ABD + (-3.89)ACD + (0.18)ABCD$$

6. For water the equation is

$$T_o = 58.43 + (-0.294)A + (0.56)B + (0.64)C + (-7.018)D + (0.23)AB + (0.22)AC + (-2.17)AD + (0.57)BC + (-4.27)BD + (2.356)CD + (0.144)ABC + (0.58)ABD + (0.82)ACD + (1.17)BCD + (0.144)ABCD$$

Where A =T_i, B =U_{asp}, C =U_p, D =C_s, E = (ABC) = P_{i-air},F =BCD = M_s.

Chapter-5 presents the conclusion of the experimentation, the discussion of the application of the developed model in various industries over a wide range of system parameters and the extension of further work.

Appendix-1 presents the tables of the data collected for the model development and other experimental datas for effect of various system parameters.

Appendix-2 presents the plots obtained for finding the exponents of individual parameters, the plots of effect of the various system parameters, phots obtained from SEMand FTIR & TGA plots.

Nomenclature

a,b,c,d,e,f ,n	: Exponents
To	: Outlet temperature, ^{o}C
Y	: Percentage yield
Ti	: Inlet temperature, ^{o}C
Uasp	: Aspirator Speed, kg/cm^2
Up	: Pump flow rate, ml/ min
Piair	: Atomization rate, kg/cm^2
Cs	: Concentration of salt, gm/ml
Ms	: Moleccular weight of salt
K	: Coefficient of the correlation
$(NH_4)_2SO_4$	: Ammonium Sulfate
NaCl	: Sodium Chloride
Na_2SO_4	: Sodium Sulfate
$C_6H_{14}O_6$	: Mannitol

Suffixes:

1 : outlet temperature

2 : % Yield

‘ : water

ANN: Artificial Neural Network.

CHAPTER-I

Introduction

Spray drying is the most widely used industrial as well as laboratory process for particle formation and drying. The spray drying is a continuous operation in which almost any pumpable liquid can be converted into a free flowing powder. The feed stalks can include solutions, emulsions and pumpable suspensions. The technology is ideal when the end product must comply with precise quality standards [1]. This regards particle size distribution, residual moisture content, bulk density and particle morphology.

The process involves conversion of fluid into fine droplets and exposing them to a hot drying media, so as to achieve defined dry particulate matter. The liquid feed is pumped through an atomizer device that produces fine droplets into the main drying chamber. Atomizers vary with rotary, single fluid, two-fluid and ultra-sonic designs. These different styles have different advantages and disadvantages depending upon the application of spray drying required. The hot gas is normally air but sensitive materials such as pharmaceuticals and solvents like ethanol require oxygen-free drying and nitrogen gas is used instead. The hot drying gas can be passed as a co-current or counter-current flow to the atomizer direction. The co-current flow enables the particles to have a lower residence time within the system and the particle separator (typically a cyclone device) operates more efficiently. The counter-current flow method enables a greater residence time of the particles in the chamber.[2-9] The thermal energy of the hot air is used for the evaporation and the cooled air pneumatically conveys the dried particles in the system. The contact time of the hot air and the spray droplets is only a few seconds, during which drying is achieved and the air temperature drops instantaneously. The dried particles never reach the drying air temperature. This enables efficient drying of heat sensitive materials without thermal decomposition. Dried powder is continuously discharged from the drying chamber and recovered from the exhaust gases using a cyclone or a bag filter.

Ranges of spray dryers vary from laboratory scale to industrial huge dryers. Small R&D spray dryers are useful for many situations and testing requirements, including feed formulation studies, producing samples for testing and determining optimum drying conditions. But in many cases and for many products, laboratory spray dryers that are too small for producing the desired particle size, or for predicting the other physical properties that can be achieved in production scale spray dryers.[10]

Spray drying is an essential unit operation for the manufacture of many products with specific powder properties. Spray drying is used for the manufacture of many consumer and industrial products such as instant food products, laundry detergents, pharmaceuticals, ceramics and agrochemicals. The best known example of an instant food product is milk powder, but instant beverages (e.g. coffee) can also be produced by spray drying. [11,12]Spray drying often is used as an encapsulation technique by the food and pharmaceutical industries. Spray drying has recently been used in developing pulmonary delivery systems for protein drugs. Especially, inhalation powders provide a potential way with controllable characteristics for needle-free, systematic delivery of therapeutic peptides and proteins.

Relatively high temperatures are needed for spray drying operations. However heat damage to the products is generally only slight, because of an evaporative cooling effect during the critical drying period and because the subsequent time of exposure to high temperature of the dry material may be very short. For this reason, it is possible to spray dry some bacterial suspensions without destruction of the organisms. The physical properties of the products are intimately associated with the powder structure which is generated during spray drying.[13] It is possible to control many of the factors which influence powder structure in order to obtain the desired properties.

CHAPTER-II

Literature Survey

2.1 Introduction

Different types of spray dryers are used for various purposes in different fields ranging from laboratory sale to industrial sectors. During the last three decades spray drying has undergone an intensive research and development, so that modern spray drying equipment can meet the requirements to produce a powder with tailor-made specifications required by the end-user. One of the first spray drying patents was applied for in 1901 by the German Mr. Stauf, who sprayed the milk by nozzles into a chamber with warm air. The first real break-through, however, was in USA in 1913, when the American Mr. Grey and the Dane Mr. Jensen developed a nozzle spray dryer and started to produce and sell drying installations on a commercial scale.

The first rotary atomizer was developed by the German Mr. Kraus in 1912, but not until 1933, when the Danish engineer Mr. Nyrop filed his world patent, which was the real break-through of atomization.

2.2 Unit Operations: Spray drying consists of the following unit operations:

- Pre-concentration of liquid
- Atomization (creation of droplets)
- Drying in stream of hot, dry air
- Separation of powder from moist air
- Cooling
- Packaging of product

2.3 Typical Spray Drying Systems:

The diagram shows a schematic representation of a typical spray drying system for milk powder. For spray drying, it is usual to pump a concentrate of the liquid product to the atomizing device where it is broken into small droplets. These droplets meet a stream of hot air and they loose their moisture very rapidly while still suspended in the drying air. The dry powder is separated from the moist air in cyclones by centrifugal action. The centrifugal action is caused by the great increase in air speed when the mixture of particles and air enters the cyclone system. The dense powder particles are forced toward the cyclone walls while the lighter, moist air is directed away through the exhaust pipes. The powder settles to the bottom of the cyclone where it is removed through a discharging device. Sometimes the air-conveying ducts for the dry powder are connected with cooling systems which admit cold air for transport of the product through conveying pipes. Cyclone dryers, such as shown here have been designed for large production schedules capable of drying ton-lots of powder per hour[14-16].

Typical spray dryer for milk powder

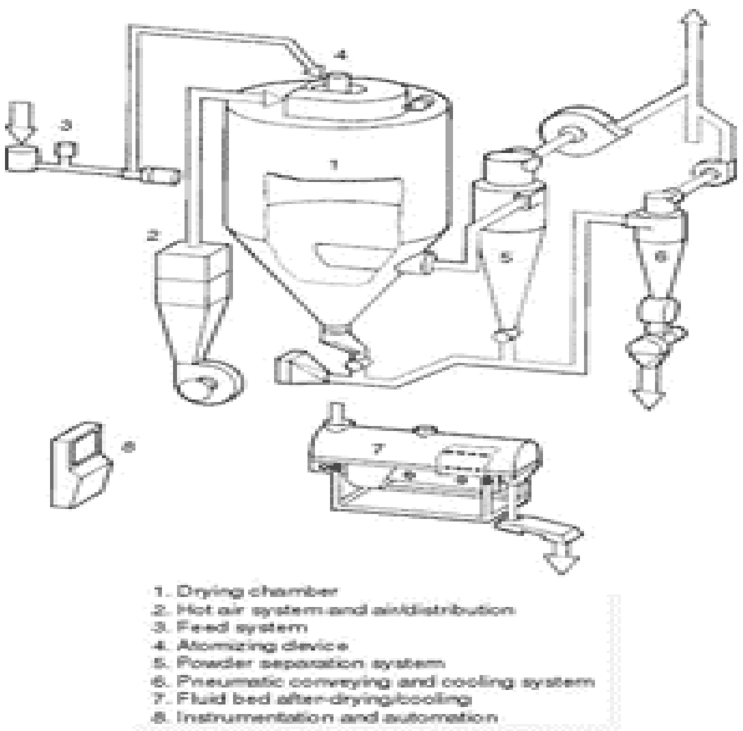


Figure-1

2.3.1 Cyclone Spray Dryer: The following is a diagram of a typical spray drying operation utilizing a centrifugal atomizer and a cyclone separator.

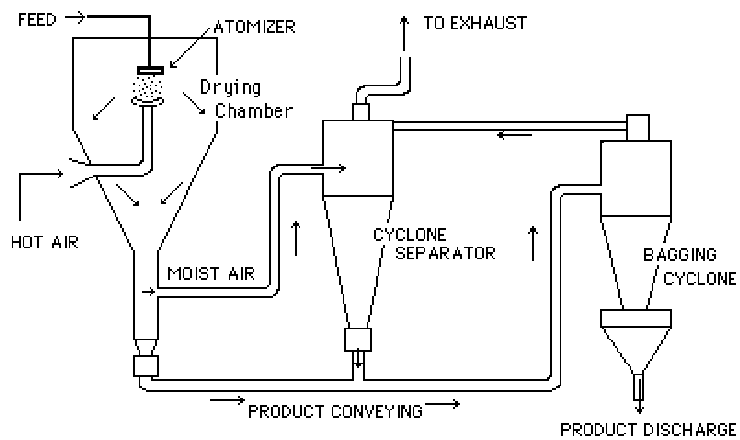


Figure-2

2.3.2 Box Spray Dryer. A different system, known as the 'Rogers Process' is shown in the next diagram. This design has been popular for relatively small production schedules and for physically sensitive powder material which may not withstand the friction generated by the cyclone action. In this process, filtered air is preheated with steam or gas and is blown into ductwork (A) and then into the specially proportioned distributing head (B), passing through air inlets to the drying chamber (C). The hot air absorbs the moisture from the finely divided, atomized liquid spray and passes under air baffle (D) to cloth filter bags (E) where 100% of any remaining powder is trapped from the exhaust air. .[17,18] The filter bags are intermittently shaken by a mechanical device to release any adhering powder which then drops to the floor and blends in with the remaining powder

Rogers Spray Drying Process.

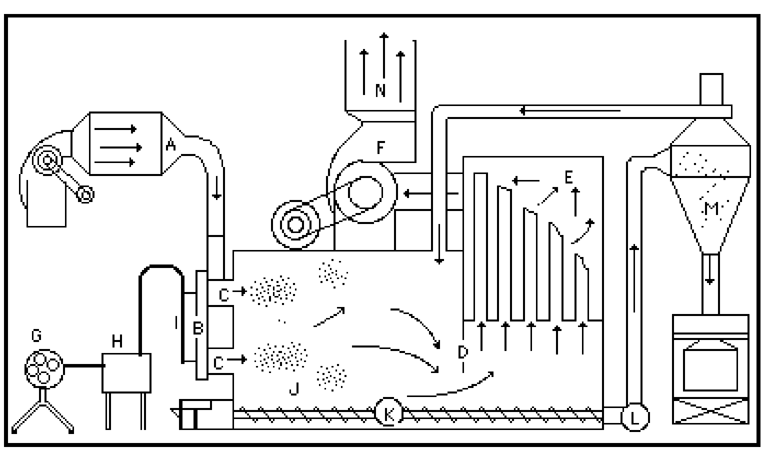


Figure-3

The moist air is then exhausted to the atmosphere through the exhaust fan (F). Liquid to be dried is preheated in heater (G), passing to a high pressure pump (H), through the high pressure line (I) to spray nozzles located in air inlets (C). The atomized liquid droplets are dried while suspended in the chamber and the powder settles to the floor where it is conveyed by a reciprocating scraper (J) to the screw conveyor (K). The powder moves to the chamber outlet (L) where it is may be removed manually or picked up by an optional pneumatic system to a cyclone separator (M) which cools the powder with fresh air. A sifter is located below the cyclone discharge.[18]

2.4 Pre-Concentration of Liquid Feed. For operation of a spray dryer it is usual practice to pre-concentrate the liquid as much as possible. There are several reasons for this :

• Economy of operation (evaporation is less expensive)

• Increased capacity (amount of water evaporation is constant)

• Increase of particle size (each droplet contains more solids)

• Increase of particle density (reduction of vacuole size)

• More efficient powder separation (related to increased density)

• Improved dispersibility of product (reduction in surface area)

First, it must be recognized that water removal in a vacuum evaporator and in a spray dryer are two very different processes. Evaporation under vacuum is a process which takes place at a much lower temperature than spray drying. Generally, the temperature of the first stage is only Å 65 C and subsequent stages even less[19]. For this reason, vacuum evaporation in multiple stages permits the use of low-cost energy and regeneration of the energy contained in the vapor removed from the product. In principle, very little heat energy is used or lost during vacuum evaporation.

In contrast, spray drying takes place at atmospheric pressure; therefore, the drying air needs to be heated to high temperatures, generally around 150-175 C. This requires high-cost fuel in the form of gas or oil. Besides, there is almost no opportunity to regenerate the energy from the vapor phase. Thus, for efficient industrial spray drying operation, it is usual to combine the two processes.

Next, it must be recognized that the performance of a spray dryer is rated according to the maximum amount of water which can be removed per hour by that system. For example, a spray dryer rated at 1000 kg/hr water evaporation will produce only Å111 kg/hr of bone-dry powder from a liquid of 10% total solids. If that liquid is concentrated to 45% total solids, the powder production increases to Å818 kg/hr of bone-dry powder.

Finally, the powder structure and, therefore, the physical properties of a powder is very dependent upon the total solids concentration of the liquid which is being dried. If the droplets are maintained at a constant size, then, the amount of solids will affect both the size and the density of the dry particles. The structure of a spray-dried particle is a hollow sphere, with the solids being a shell which surrounds a central vacuole. As the total solids of the feed increases, the shell becomes thicker and, as a consequence, the particle does not shrink as much during drying. Similarly, as the air-filled vacuole decreases in size, the particle density increases. The increase in particle density has a pronounced influence on the efficiency of powder separation/collection by the cyclones, because these operate on the principle of a difference in the buoyant density difference between air and particles. It is well-known in the spray-drying industry that drying a liquid of low solids content is the cause of very fine particles which are difficult to collect. This results in product losses as well as environmental pollution when they are discharged into the atmosphere.

2.4.1 Limitations on Pre-Concentration: The limit on the extent of pre-concentration of the feed is dictated by the viscosity of the liquid, which must not be so high, that the product cannot be pumped or atomized. For milk powder manufacture, it is common to pre-concentrate the milk (9% total solids in skim milk; 13% total solids in whole milk) to 45% in an evaporator. For many protein isolates, such a high concentration cannot be used, because most protein solutions are very viscous.[20] In this case, spray drying must be done with a concentrate of about 25% total solids concentration. This practice, however, causes the powder particles to have a lower density. Therefore, these products are typically very light and fluffy and the unit cost of operation increases dramatically.

2.5 Atomization: In spray dryers the powder quality depends upon various parameters. Atomizer is one of the product specifier. The size and uniformity of droplets are determined by the atomization. Different types of Atomizers are Rotary Atomizer, Two-fluid nozzle, co-current mode Atomizer, Two-fluid nozzle, fountain mode Atomizer.

2.5.1 Rotary Atomizer: Atomization is achieved by feeding liquid into a high-speed wheel. The rotary atomizer as shown in Fig.-4 is placed in the ceiling air disperser and operates with a vaned atomizer wheel for non-abrasive feeds, and with a carbide bushing wheel for abrasive feeds. Other designs are available for special applications. Powders produced with this atomizer mode have a narrow particle size distribution with a mean size in the range of 20-50 μm[7].

2.5.2 Two-fluid nozzle, co-current mode Atomizer:

Atomization is achieved by using compressed air to atomize the liquid feed. The nozzle placed in the ceiling air disperser (Fig.-5) is ideal for heat sensitive feeds and has the added advantage of handling both low and high viscosity feeds. Powders produced with the co-current two-fluid nozzle have a mean particle size in the range of 10-40 µm[21,22].

2.5.3 Two-fluid nozzle, fountain mode Atomizer:

The nozzle placed in the cone section of the drying chamber (Fig.-6) is spraying upwards countercurrent into hot air from the ceiling air disperser. The fountain mode has the advantage of spray drying high solids feeds, and producing free-flowing powders of a mean particle size in the range of 60-100 µm.

2.6 Spray dryers used in food and dairy industry: The following spray dryers are the most commonly used in the food and dairy industry. They are as discussed below.

2.6.1 Conventional Two-Stage Spray Dryer :

A spray dryer layout featuring either a rotary atomizer or spray nozzle atomizer is as shown in Fig.-7. Powder discharged from the drying chamber can be further dried and cooled in a vibrating fluid bed. This two-stage drying concept achieves better overall heat economy and is suitable for many food and dairy products. When non-agglomerated powders of non-fat products are dried, a pneumatic transport system can replace the fluid bed[22,23].

2.6.2 Compact Spray Dryer:

A space saving spray dryer with integrated fluid bed is as shown in Fig.-8. Atomization is created by either a rotary atomizer or spray nozzle atomizer. The location of the fluid bed within the drying chamber permits drying to be achieved at lower temperature levels resulting in higher thermal efficiencies and cooler conditions for powder handling. The plant can be equipped with pneumatic transport system for many powders or with an external vibrating fluid bed for agglomerated powders.

2.6.3 Fluidized Spray Dryer - FSD™ (Food and Chemical):

The Fluidized Spray Dryer (FSD™) (Fig.-9) combines spray drying and fluid bed drying technologies and offer excellent product flexibility and excellent thermal efficiency. Pressure nozzles or a rotary atomizer spray the feed down towards the fluid bed where agglomeration incorporating finer, recycled material takes place. Exhaust air outlet is let through the roof causing further agglomeration in the spray zone. Sticky products can be dried successfully, and the concept is ideal for drying heat sensitive products, and improved aroma retention is accomplished. Product-agglomerated (instant), free-flowing dustless powders, agglomerated powders are obtained in systems based upon the integrated fluid bed or belt and a multi-stage concept where moist powder, produced during the first drying stage, forms agglomerates, which are after-dried and cooled in the following stages.

2.6.4 Multi-Stage Dryer - MSD™ (Dairy):

The spray is created by a spray nozzle in the atomizer of this unit as shown in Fig.-10. Operational flexibility enables production of a wide range of physical properties. The process produces non-dusty, free flowing agglomerated powders with high flavor retention. It operates with low outlet-temperatures, achieving high thermal efficiency. Dry ingredients for additional flavor or nutrient fortification can be added within the system to further promote capabilities and improve formulation efficiencies. This design concept is successful for drying high fats, hygroscopic, and sticky products that are difficult to handle in more conventional designs(6).

2.6.5 The Integrated Filter Dryer (IFD™):

IFD™ Integrated Filter Dryer as shown in Fig.-11, combines an integrated fluid bed and filter arrangement. It is a adaptable and flexible spray dryer for the food ingredients, food, dairy, chemical, and pharmaceutical industries.

The Integrated Filter Dryer (IFD™) features and benefits:

- Improves powder quality
- Total in-place recovery of powder
- Features integrated fluid bed
- No handling of product outside drying chamber
- Compact plant layout
- Reduced noise level
- Lower energy consumption

2.6.6 Tall Form Dryer™ – TFD:

A tower spray dryer with a top mounted nozzle assembly featuring a fines return capability is as shown in Fig.-12. The atomized droplets dry while gently falling down the tower. Further drying and cooling are carried out in a vibrating fluid bed located under the tower. The TALL FORM DRYER™ is suited for both non-fat and fat-containing products, producing non-agglomerated and agglomerated free-flowing powders.

2.6.7 Filtermat® Dryer:

The Filtermat® Spray Dryer (Fig.-13) is frequently used in food and dairy applications. It operates at a low outlet temperature, achieving high thermal efficiency. It is the recommended system for drying high fat, sugar-based, hydrolyzed, and fermented products.


Figure-4


Figure-5


Figure-6


Figure-7

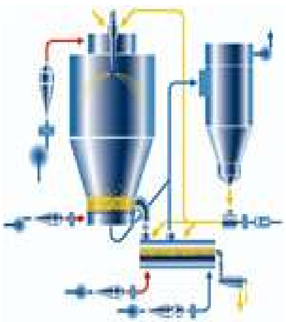


Figure-8

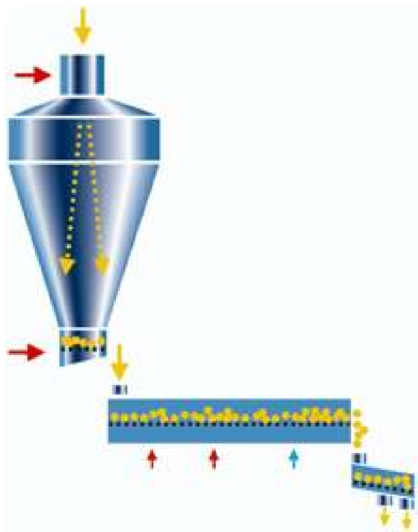


Figure-9


Figure-10

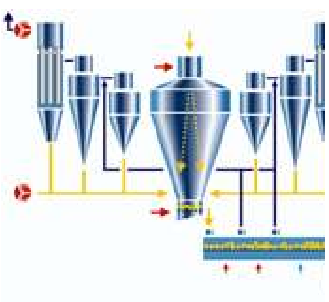


Figure-11

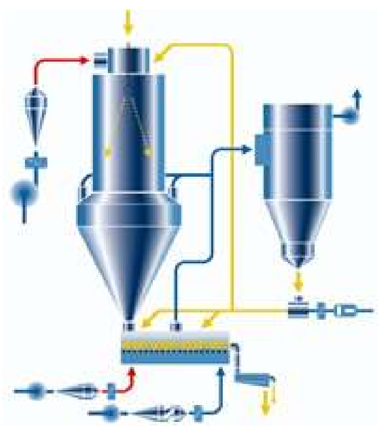


Figure-12

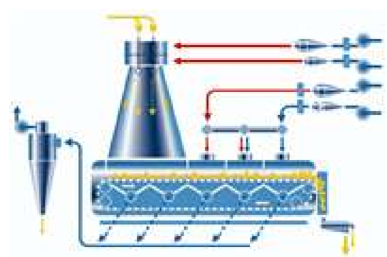


Figure-13

2.7 Heat and Mass Transfer in the Dryer:

There are only few details known about actual heat- and mass-transfer processes in the drying chamber. However the history of drying in a single droplet can be constructed

2.7.1 Drying of a Droplet.

- In the initial period, the temperature increases to the wet bulb temperature.
- In the second period, a concentration gradient builds up in the drop and water activity at the surface decreases, thus causing the surface temperature to rise above that of the of the wet bulb temperature.
- In the third period, internal diffusion becomes limiting. A critical moisture content is eventually reached below which the surface becomes impenetrable.

The drying time for a single droplet may be estimated by the following equation:

$t = [r^2 d_L ÆH_V\ ] \times [m_i\text{-}m_f] / [3h(ÆT)] \times [1+m_i]$ ....(2.1)

where, t= time (hr); r = radius of droplet; d_L = density of liquid (lb/ft^3); $ÆH_V$ = latent heat of vaporization (Btu/lb); m_i = initial moisture content (lb H_2O/lb dry food); m_f = final moisture content (lb H_2O/lb dry food);
h = film coefficient for heat transfer (Btu/ft^2/hr/°F); ÆT = temperature difference between initial and final stages (°F).

The typical drying time for an average milk droplet of 40 µ is only a fraction of a second. However, because of the great initial velocity, the particle will have traveled a considerable distance from the atomizer before it is dry (13.5 cm for average conditions). It should be noted, that the drying time is proportional to the square of the radius; thus, for larger droplets the drying time may become so long that the droplet reaches the wall of the dryer while still wet. This problem is often encountered in small scale dryers. The above equation also stresses that the drying time can be shortened by reducing the initial moisture content by pre-concentration of the liquid.[24]

2.7.2 Separation of Dry Particles: Separation is carried out partly within the drying chamber itself and partly in secondary separation equipment. In general, it is easy to remove 90% or more of the powder, but removal of the remainder becomes problematic. Cyclone separators operate on the 'momentum separation' principle (centrifugal action) and are extensively used in large scale dryers for removal of fines.

2.8 Application Spray drying is suited for most real and colloidal solutions and dispersions as long as the dried product behaves like a solid

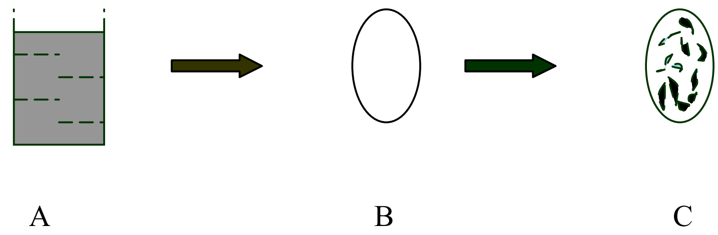


Figure-14

An aqueous solution of the product (A) is sprayed as fine droplets (B) in the device. The solvent vaporizes immediately surrounding the product in a vapor cloud that protects the product from thermal influences. Shortly thereafter the solvent on the surface as well as inside the "kernel" vaporizes, creating the corresponding pores. The final product (C) is a fine, amorphous material. Spraying a highly concentrated solution result sin a more porous final product than spraying a solution with lower content of solid material.[18,25]

Examples:

Table-1

Product	**Inlet °C**	**Outlet °C**	**Spray concentration %**
Foodstuffs			
Low fat milk	174	102	50
Yeast	95	65	60
Aroma/Cosmetics			
Beer Concentrate	150	110	30-40
Olive leaf extract	150	90	36
Medical/Pharmaceutical			
Blood plasma	180	100	5
Peptides	110	70	2
Chemical products			
Dispersion dyes	150	95	20

2.8.1 Micro encapsulation

In micro encapsulation a liquid product such as oil is embedded in a solid or a mixture of solid compound. This protects the oil from environmental influences such as oxidation or loss of aroma and also places the product in a "solid form".

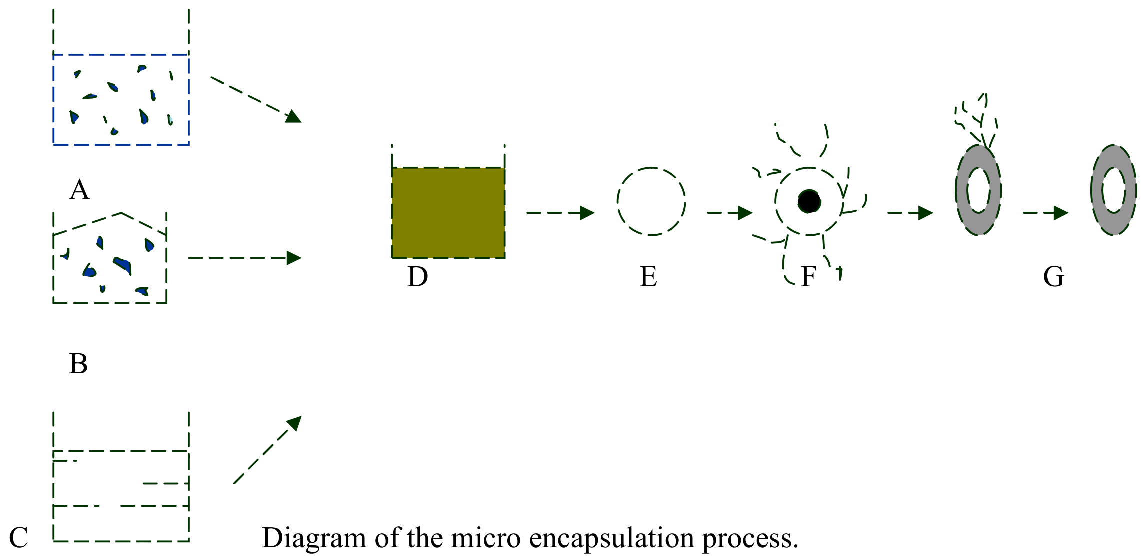


Diagram of the micro encapsulation process.

Figure-15

An emulsion (D)is created from the liquid product to be treated (A), a carrier substance (B) such as maltodextrin and a filmogen solution (C) such as gum Arabic in water. Thus emulsion is then homogenized in the apparatus into small droplets (E) and sprayed. The solvent vaporizes while building a surface just beyond the surface of the core, whereby the solvent now trapped in the inner volume of the droplet creates a vapor buddle (F). As the drying process continues, the pressure in the trapped vapor bubble increases until the droplet created bursts, creating a small eruption opening.[18,33] The result is that the smallest droplet of the product(A) are stored in the carrie substance(B) and embedded in the filmogen.

Examples

Table-2

Product	**Inlet ^{o}C**	**Outlet ^{o}C**	**Spray concentration %**
Foodstuffs Soyabean oil in maltodextrin /gelatin	150	90	30
Aroma/Cosmetics Aroma, strawberry in maltodextrin/gum Arobic 1.5:1.5:3	150	90	35
Medical/Pharmaceutical Guajazulene in maltodextrin/gumArobic 1:2:1	120	70	Ca.30

2.8.2 Englobin

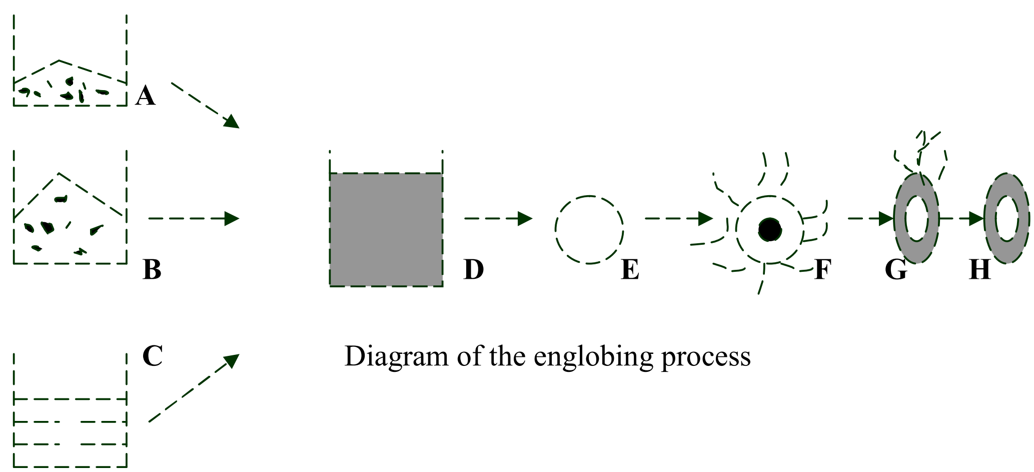


Diagram of the englobing process

Figure-16

The englobing process is analogous to the microencapsulating process, whereby a solid material is used instead of a liquid product. A solution or dispersion(D) is created from the product to be treated (A), filmogen (B) and water (C), This solution is then sprayed into small drops (E). The droplets dry under the subsurface and create a more or less compact surface skin and a vapor bubbles created in the inner volume of the droplet (F), As the drying process continues, the pressure in the trapped vapor bubble increases until the droplet created bursas and the solvent trapped inside escapes(G). The result here is also small, hollow balls, whereby the product to be treated(A)is embedded in the walls of the hollow ball(filmogen)(H).[18,326]

Example

Table 3

Product	**Inlet ^{o}C**	**Outlet ^{o}C**	**Spray concentration %**
Foodstuffs Inverted sugar (date pulp)in lactose1:1	100	80	20
Medical/Pharmaceutical Streptococci in low fat milk powder/glucose/gelatin1:1:1:3	90	70	40

2.9 Structure of Spray Dried Powder Particles. The structural features of a spray-dried particle are illustrated in the following diagram. Buma (1971) has used scanning electron microscopy to study the particle structure and the distribution of free fat in the particles. He has shown that spray drying results in hollow particles, the shells of which have a glassy structure, primarily of amorphous (non-crystalline) lactose. Pure lactose dries into spherical particles with no dents or folds, whereas skim milk, caseinates and other proteins always give rise to surface folds. Buma and Henstra (1971) have explained that proteins, unlike lactose and other sugars, shrink unevenly during drying.

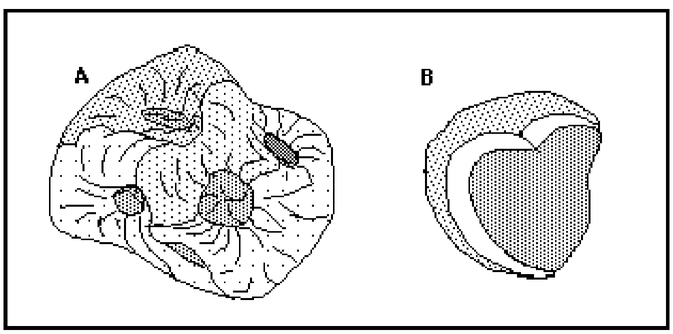


Figure-17

The physical properties of spray dried powders is related to the characteristics of the matrix of the shells and to the size of the vacuole. The presence of the vacuole causes the particles to have a lower density than the solid itself (0.33g/cc versus 1.6 g/cc). Generally, powders with low density are fluffy and do not wet or sink readily when brought in contact with water. Sugars, such as lactose in milk powder, do not crystallize during drying but are present in an amorphous state. Such amorphous sugars are very hygroscopic and readily absorb moisture and eventually recrystallize. This is the cause for many powders caking during storage.[18,27] Recrystallization is usually accompanied by changes in color and development of off-flavors Some sample pictures of powders obtained from spray dryer viewed by Scanning electron Microscope.

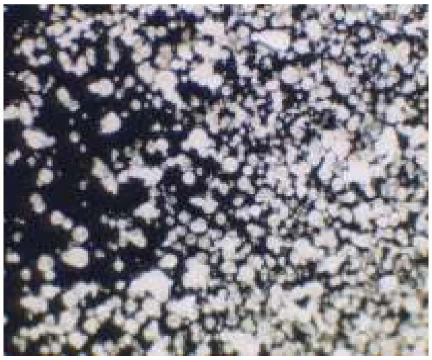


Figure-18

Figure-19

Fig.-18 is in 29 magnifications for the powder from producing by the spray dryer, it seems to be mere powders. Fig.-19 is in 175 magnifications. Each particle is forming spherical ball which is most excellent point of powder from the spray dryer.

2.10 Dispersion Characteristics of Spray Dried Powders. Many spray-dried powders do not disperse readily in water. The difficulties are associated with the exterior of the powder absorbing water very rapidly and forming lumps, dry on the inside but covered with a viscous layer through which water penetrates very slowly. The problem arises particularly in products which contain soluble proteins, such as milk powder and flour. Karel (1975) has discussed the requirements for rapid dispersibility of powders in cold water. The following properties are desired [22,28].

• A large wettable surface
• Sinkability (must not float on surface)
• Solubility
• Resistance to sedimentation

The wettability is crucial and depends upon the total surface area of the powder and on the surface properties of the powder particles. The spray drying industry in Western countries have improved the dispersibility characteristics of their products by a combination of surface treatments (for example addition of lecithin) and 'instantizing' (agglomeration). Instantizing is an aggregation process which is intended to prevent powder particles from sticking together and becoming lumpy during rehydration.

2.10.1 Instantized Powders. 'Instant' powders are usually produced by processes in which the spray-dried powder is first wetted and then redried. The degree of rewetting is closely controlled (Å15%) to permit the particles to stick together and form aggregates before redrying. In these products the small particles are fused together but the points of contact are so few that practically all of the surfaces are available for wetting. The aggregates, however, are sufficiently stable to prevent lumping when stirred into water. During the rewetting procedure, lactose will partly crystallize. Therefore, instant powder is less hygroscopic. The following is a flow diagram of the instantizing process and a schematic representation of particle agglomeration.

2.10.2 Particle Agglomeration after Instantizing Process. In the following diagram, A is a representation of regular powder. B represents aggregates from drying a rewetted powder

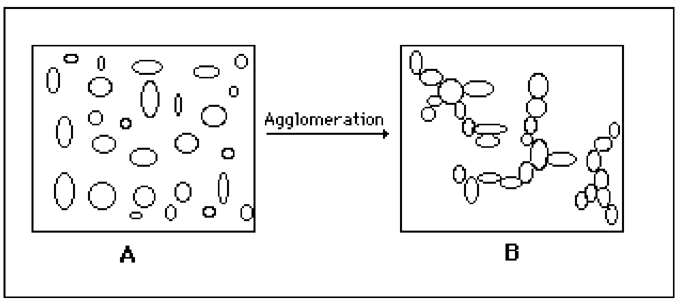


Figure-20

2.11 Selection of Operating Conditions: The most important responsibility for an operator of a spray drier is to maintain constant moisture content of the powder. This is required to meet legal standards and for maintaining a uniform quality. Average operating conditions for spray drying of milk powder will vary somewhat depending upon the dryer system used and must be adjusted to produce the desired uniform moisture content. It is important to understand how the final moisture content can be controlled by changing the conditions. But first, it should be noted that the final moisture content is controlled by the relative humidity of the outlet air [22,30]. If that value is too high, then the powder particles will absorb moisture rather than give moisture away. The primary conditions which may be controlled directly by the operator are:

- Inlet temperature (setting of thermostat)
- Flow rate of liquid feed (pump speed; pump pressure)
- Air flow rate (fan speed; position of baffles)
- Particle size (adjustment of atomizer)

Among other operating conditions, outlet temperature and relative humidity of the outlet air are particularly important and need careful attention. However these can only be indirectly controlled by adjusting the primary conditions.

For outlet temperature, the condition is dependent upon liquid feed intake. If the feed intake is increased, the outlet temperature will drop. If the intake is reduced, the outlet temperature will increase and approach the inlet temperature. The outlet temperature will also be affected by the air flow rate[22,30]. For a constant inlet temperature and constant feed intake, an increase in the air flow will raise the outlet temperature.

2.12 Factorial Design:

Full Factorial Design in two levels: The factorial experiment with two factors at two levels can be analyzed by the formal method for factorial designs. There are features about 2^n factorial which make its use in experimental work particularly attractive. First, the analysis of variance can be carried out in much simpler manner than that employed for the general balanced factorial design. Second, when large numbers of experiments are involved, the sequence of experiments can be arranged so that differences among groups of experiments can be equated to higher order interactions and the main effects and lower- order interactions can be determined without any interference. Third the 2^n factorial lends itself to fractionation so that results can be obtained from a half or a quarter of the total factorial experiment.

A common experimental design is one with all input factors set at two levels each. These levels are called `high' and `low' or `+1' and `-1', respectively. A design with all possible high/low combinations of all the input factors is called a full factorial design in two levels. If there are k factors, each at 2 levels, a full factorial design has 2^k runs.[41]

Table-4

Number of Runs for a 2^k Full Factorial	
Number of Factors	**Number of Runs**
2	4
3	8
4	16
5	32
6	64
7	128

As shown by the above table, when the number of factors is 5 or greater, a full factorial design requires a large number of runs and is not very efficient. a fractional factorial design is a better choice for 5 or more factors.

Fractional factorial design: In statistics, fractional factorial designs are experimental designs consisting of a carefully chosen subset (fraction) of the experimental runs of a full design. Fractional designs are expressed using the notation l^{k-p}, where l is the number of levels of each factor investigated, k is the number of factors investigated, and p describes the size of the fraction of the full factorial used. Formally, p is the number of generators, assignments as to which effects or interactions are confounded. A design with p such generators is a $1/(l^p)$ fraction of the full factorial design.[(42)] The levels of a factor are commonly coded as +1 for the higher level, and -1 for the lower level.

2.13 Artificial Neural Network method for calculating outlet: An ANN method is a computing system made up of a number of simple and highly inter-connected processing elements, which processes information by its dynamic state response to external inputs as discussed by Wasserman P.D.[(43)] and Chitra S.P.[(44)]. The back propagation network systems as studied by Rumelhart et al.,[(45)] A three layered feed forward Neural Network is considered for this problem. The network is trained for a given set of input and target data sets. These sets were obtained from the experimental observations. The network is trained with a certain number of data sets for blank solution and salt solution. For water (blank solution) each set consists of four system parameters and the corresponding experimental value of the outlet temperature, where for salt solution each set consists of six system parameters and the corresponding experimental value of the outlet temperature and the yield. The data were scaled down and then the network was exposed to these scaled data sets.

2.13.1 ANN- Data processing procedure: The program involves a forward propagation step followed by a back-propagation step. Both the forward and backward propagation steps are followed for each pattern presentation during training. The forward propagation step begins with the presentation of an input pattern to the input layer of the network and continues as activation level calculations propagate forward through the hidden layers. In each successive layer, every processing unit sums its input and then applies an activation function to compute its output. The output layer of units then produces the output of the network. The backward propagation step begins with the comparison of the network's output pattern with the target vector and the difference, or 'error' at the output layer is then calculated. The output layer weights are updated using these errors. The backward propagation step then calculates the error values for hidden units and changes for their incoming weights, starting with the output layer and moving backward through the successive hidden layers. In this back propagation the network corrects its weights to decrease the observed error.

The network structure together with the learning rate was varied to obtain an optimum structure with a view to minimize the mean square error at the output.

The training data sets were impressed repeatedly till the mean square error is below a prescribed threshold. The weights obtained from the training are now used for predictions. The network with these weights is now exposed to the prediction data set and thereby the required number of sets of output data in each of the cases was computed.

The final outputs computed by ANN- approach were found by averaging all the sets of output data component wise and then multiplying with the respective scaling factor.

CHAPTER III

EXPPERIMENTAL ASPECT

The experimentation is carried out using mini spray dryer whose specifications are mentioned below.

3.1 Experimental set-up:

Equipment: **LAB SPRAY DRYER**

Model: **LU-20**

Year of Manufacture-**2007**

The experimental set-ups primarily consists of the following major components

1. Filter - For pre filtration of air and absolute filtration at system intake of fresh air.

2. Air heater - For heating the inlet air to desired /set temperature.

3. Air distributor - For uniform distribution of hot inlet air in drying chamber.

4. Drying chamber - Drying of fine atomized feed spray takes place in drying chamber.

5. Collection bottle - for collection of heavy particulates if any.

6. Cyclone - For separation of fine particles from spray dried mass conveyed from drying chamber.

7. Collection pot - For collection of fine particulates from the cyclone.

8. Scrubber - for trapping the ultra fine not separated in the cyclone.

9. Aspirator Assembly - for controlled air flow rate and vacuum through the system.

10. Electronic Control Panel - The electronic panel is installed in microprocessor based controller with controls for variation of following parameters.

- Inlet hot air temperature
- Outlet hot air temperature
- Feed rate for atomization
- Vacuum control
- Hot air flow rate
- Process time
- Nozzle solenoid ON/OFF timing
- Nozzle Deblocking solenoid ON/OFF timing

3.1.1 Detailed Features of the equipments

Table 5

Glassware

Parts No	Details	Qty
GLU-F6-1.00	Full set of glassware	1set
GLU-P-1.01	Spray chamber	1 No
GLU- P-1.02	Collection bottle	1 No
GLU- P-1.03	Cyclone	1 No
GLU- P-1.04	Collection Pot-1st	1 No
GLU- P-1.04T	Collection Pot-2nd	1 No
GLU- P-1.05	Scrubber Chamber	1 No

Table 6

For Glassware Connection

Accessories	Details	Qty
GLU-1.00	Set of Silicon Rubber Gaskets/Rings	1 set
GLU-2.00	Set of Threaded Teflon Couplers	1 set
GLU-3.00	Complete centre piece with end threaded Couplers	1 No
GLU-4.00	Teflon Cover for collection pot-1st	1 No
GLU-4.00T	Teflon Cover for collection pot-1st	1 No
GLU-6.00	Clamp for scrubber chamber	1 No
GLU-7.00	Scrubber element complete with medii and top flange	1 No
GLU-8.00	Alkathene hose pipe from cyclone to scrubber	1 No
GLU-9.00	Alkathene hose pipe from scrubber to Aspirator	1 No

Table-7 **Hot Air System**

Part No	Details	Qty
HLU-P-2.00	Drying Air intake filter	1 No
HLU-P-2.01	Heater	1 No
HLU-P-2.02	Heater Body	1 No
HLU-P-2.03	Air Distributor	1 No
HLU-P-2.04	Aspirator	1 No

Table 8 **Accessories For Hot Air Systems**

Parts No	Details	Qty
HLU-1.00	Alkathene hose pipe from air filter to heater body with end threaded couplers	1 No
HLU-2.00	Alkathene hose pipe for Aspirator outlet	1 No

Table 9 Accessories For Compressed Air Systems

Parts No	Details	Qty
CLU-1.00	PU-6 Tube with connector	1 set
CLU-2.00	Silicon Tube with connector	1 set

Table 10 Feed System

Parts No	Details	Qty
FLU-P-4.00	Peristaltic Pump	1 set
FLU-P-4.01	Spray Nozzle	1 set

Table 11 Accessories Feed System

Parts No	Details	Qty
FLU-1.00	Master flex tubing	1 set
FLU-2.00	Set of silicon rubber ‘o’ ring for Nozzle	1 set

Table 12 Electrical control Panel

Parts No	Details	Qty
ELU-P-5	Control Panel Box	1No
ELU-P-5	Variable speed Drive	1No
ELU-P-5	SMPS Unit	1No
ELU-P-5	Control Processing Unit	1No
ELU-P-5	DAC Module	1No
ELU-P-5	ELCB Switch	2Nos
ELU-P-5	Stepper Motor Drive Module	1No
ELU-P-5	Push switch	2Nos
ELU-P-5	Glass fuse	1No
ELU-P-5	2 x 8 connector for RTD	1No
ELU-P-5	Cooling Fan	1No
ELU-P-5	16 x 4 LCD Display	1No
ELU-P-5	2 x 4 Matrix Keyboard PCB	1No
ELU-P-5	25 Pin D type Connector for Parallel Printer interface	1No
ELU-P-5	1 x x2 Connectors for Digital Input Connections	1No
ELU-P-5	25 Pin D type Connector	1No
ELU-P-5	4 x 1 Analog Output Connection	1No

Table 13 Accessories For Electrical control Panel

Parts No	Details	Qty
ELU-1.00	Wires, Connecting plugs etc.	1 set

Table 14 Instrumentation

Parts No	Details	Qty
ILU-P-6.00	RTD Sensor	2Nos
ILU-P-6.01	Pressure Gauge	1No
ILU-P-6.02	Vacuum gauge	1 No
ILU-P-6.04	Air filter cum Pressure Regulator	1 No

Table 15 **Accessories For Instrumentation**

Parts No	Details	Qty
ILU-1.00	Connectors	1 Set

Table 16 **Autojet De-blocking Attachment**

Parts No	Details	Qty
ILU-P-7.00	Pneumatic Actuator	1 No
ILU-P-7.01	Pneumatic Solenoid Valve	1 No

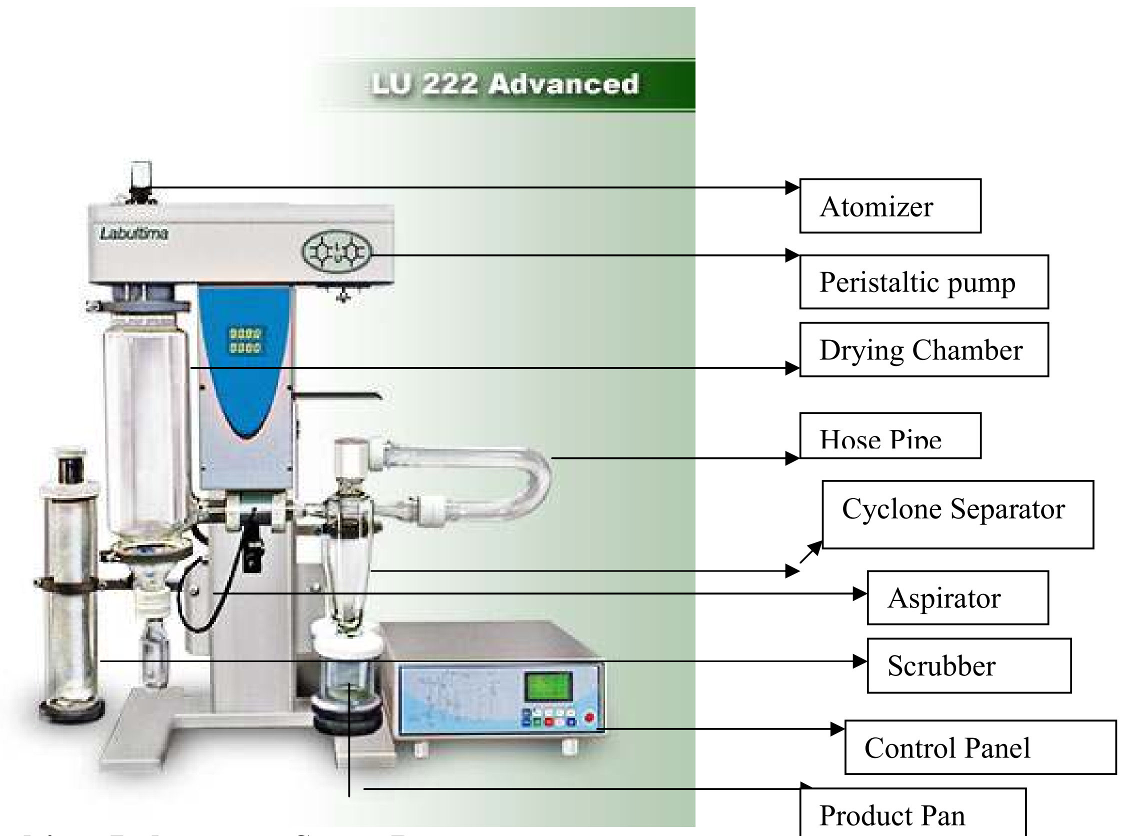
Technical Specifications

Table 17

Sr.No	Features	Specifications LU-20 Lab Spray Dryer Model (Single Cyclone)
1	Suitable for	Aqueous/ Aqueous+solvent feeds
2	Evaporation rate	1000ml of water evaporation/hr.
3	Drying Temp	Ambient to 250^{0}C; Accuracy ±1^{0}C In steps of 0.1^{0}cThrough Microprocessor
4	Air Heater Capacity	1.5 kw
5	Aspirator-Blower Capacity	85 Nm^3/hr;0 to -250mm of water column vacuum with variable frequency drive; in steps of 15 of capacity; controlled through VDF Controlled Microprocessor.
6	Aspirator Blower's Motor	0.25 HP x 2900 rpm 3 phase FLP- Motor with Single Phase 230V AC input and three phase 230V AC Output.
7	Feed Pump Capacity	1000ml/hr with 2ml ID tube 1250ml/hr with 3mm ID tube with variable speed control in steps of 1% of pump capacity controlled through Microprocessor
8	Spray System	Co-current- 0.7mm,two fluid spray nozzle
9	Deblocking System for Spray Nozzle	Manually operating
10	Hot Air Flow	Co-Current
11	**Material of construction** Main Body (stand)	SS 316- with dull GMP pharmaceutical external finish by glass bead shot blasting- Internally buffed to M-I dead mirror finish
12	Air Heater Body	SS 316
	Air Heater Element	Incolloy 80
	Air Distributor	SS 316
	Spray Nozzle	SS 316 with 2' O' Rings-0.7mm
	Drying Chamber	Borosilicate glass; annealed–stress Relieved- spark tested two piece construction for ease of cleaning-Powder removal in Assembly
	Cyclone	Borosilicate glass; annealed–stress Relieved- spark tested
	Product Receivers Collection bottle Scrubber	Borosilicate glass; annealed–stress Relieved- spark tested
	Threaded couplers	Teflon
	Connecting Tubing	Alkathene Tubing
	Cover of Product Receivers	Teflon

	Adjustable Support Stand for Receiver	Aluminium
	Tube for Peristaltic Pump	Silicon Tubing
	Scrubber Medii	3 micron pp-washable
	Fresh Air Filter	Prefilter-5 microns pp washable
	All Sealing gaskets &'O'Rings	Teflon/Silicon
	Air Pressure Regulator Cum Filter for Spray Atomization	Lagris Make 0-10 kg/cm^2
13	Built in Control System	Microprocessor based system
14	Power Supply	Variable frequency drive for Aspirator Motor housed in control panel
		The Microprocessor circuit will with 24V power supply for input interrogation and for powering DC Relays.
		ELCB protection is provided for • 2 Pole ELCB for Mains Incoming 220V-Single phase Supply 2 Pole MCB for electric Heater
		• Control Panel is provided with 1 no. isolation relay
		SSR is provided for 1.5kw Elect. Heater
		2 nos Temperature Transmitters are provided for PT 100 resistance input and output 4-20MA for inlet/ outlet temperature control.
		The system is provided with serial port data logging of inlet/outlet temp; hot airflow rate, feed pump flow rate
		Single Phase 220V, 50HZ
15	Max Current Drawn	8to 12 Amps totally
16	**Overall Dimensions**	
	Main Spray Dryer	On lab table 70 x 70 x 100 cm
	Fresh air Filter	On lab table 25 x 25 x 40 cm
	Air Compressor	On ground 40 x 40 x 40 cm

The Spray Dryer used in the lab for the experiments to be carried out.



Labultima Laboratory Spray Dryer

Figure-21

3.2 Experimental Procedure

Before starting the spray dryer, it must be noted that the compressor must be moisture free. The needle valve of air supply is opened and the air pressure regulator is adjusted to desired value of atomization pressure. Main switch is on, then in computer the parameter is set. The display on the computer shows the temperature of the four channel one below another.

1 Inlet Temperature:-The required inlet temperature is set.

2. Outlet Temperature:- The required outlet temperature is set.(the difference between the inlet and outlet temp should be 30-40^{o}C)

3. Tube Temperature:- (MAX.250^{o}C) Tube temperature is optional hence 00 is set.

4. Plate temperature:- (MAX.250^{o}C) Plate temperature is optional hence 00 is set.

5.Cool Temperature:- (MAX.250^{o}C) Cool down temperature.00 is set.

6. Inlet High Temperature:- (250^{o}C) High Temperature limit for inlet temperature for alarm for particular feed. Here 220 ^{o}C is set.

7. Outlet High Temperature:- (250 ^{o}C) High temperature limit of outlet temperature for alarm for particular feed.160 ^{o}C is set.

8 .Aspirator Speed (Max.99%):- The Aspirator speed is set in %of full scale capacity. (185 mmWC @100% Capacity).By regulating the aspirator speed, the amount of heated drying air can be increased or decreased and the under pressure value in the apparatus can be set to 30-50 mbar.

9. Feed Pump Speed:- (Max. 99%) The desired feed pump speed is set in % of full scale capacity. (1500ml/Hr of water @100% Capacity)

10. Plate Speed:- (MAX99%) The desired plate motor speed is set 00 (optional)

11. D Block On:- The deblocking solenoid valve is set on for time in sec,01 is set.

12. D Block Off:-The deblocking solenoid valve is set off for time in sec. 90 is set.

13. Cycle Time:-The process time is set in minutes.225 is set.

Once the programming parameters are set, then the program is run. The PC will log the set parameters of inlet / outlet temperature. Aspirator motor starts running at the set speed. Plate motor starts running at the set speed (Optional).Inlet air heater electric supply is on heating in order to increase inlet air temperature to the set point. The controller checks the position of the "Control Select Switch". If the switch is not in reverse control, the feed pump and nozzle solenoid will be switched on as soon as outlet temperature reaches the set outlet temperature. When "Control Select Switch" is in reverse control position, the feed pump/ nozzle solenoid are stopped, if outlet temperature reaches the set value. When cycle time reaches the set cycle time, all the heaters are switched off. Function of D'Blocking and Aspirator continues till the inlet temperature falls below the set cool temperature.

Initially the Feed pump speed and Aspirator speed calibration is carried out for three set readings. These are shown in the tables-45,46 and fig-40, 41..

3.2.1 For Water

As there are 4 different inlet parameters such as Inlet temperature, Aspirator Speed, Feed Pump Speed and Atomization Rate (Inlet Air Pressure) can be varied to observe the outlet temperature for water. Hence keeping three parameters constant one parameter is varied for one set reading to observe the outlet temperature. The variation of a single parameter is taken for 4 different readings. So total13 sets readings are taken for water. For one set reading first the parameter is set, and then the Start option is clicked in the computer. First the Aspirator and the Heater are switched on. The spray dryer is run for air till the outlet temperature attains steady state. After the steady state temperature reached the feed pipe is inserted inside the water beaker and the process is run till another steady state outlet temperature is reached. This temperature is noted down, and the set parameter is changed for another set reading. The procedure is repeated.

3.2.2 For salts

Four different salts are taken for the experimentation. They are Ammonium Sulfate $(NH_4)_2SO_4$, Sodium Chloride (NaCl), Sodium Sulfate (Na_2SO_4) and Mannitol($C_4H_{14}O_6$).

In this case there are total 6 different inlet parameters and 2 outlet parameters. The inlet parameters are Inlet temperature, Feed pump speed, Aspirator speed, Atomization rate (Inlet air pressure), concentration of salt solution and different salts with varying molecular weight, and the outlet parameters are Outlet temperature and % Yield of salt recovery. Here keeping 5 inlet parameters constant one parameter is varied at a time to observe the variation in Outlet temperature and weight of salt collected after drying. The variation of a single parameter is done for 4 times, hence a total of 19 set readings are taken for salt solution.

For one set reading, first the parameter is set in the computer, and then the Start option is clicked. Initially the spray dryer is run with air as feed till a steady state outlet temperature is reached. After steady state temperature has been reached the feed pipe is inserted in the water beaker (Base solution) and the process is carried on till another steady state temperature is reached. Once the outlet temperature is steady, the feed pipe is inserted in the salt solution of desired concentration. The reading is noted down when the final steady state temperature is reached. Then in the computer again parameters are varied to cool down the system temperature. Once the inlet temperature comes below 90^o C, the process is stopped by clicking the Stop option. After taking one set reading the entire set-up is dismantled, and the salt is collected from drying chamber, cyclone separator and the product pans.

The glassware, hose pipe and the scrubber bag are cleaned with soap solution and dried .Again the spray dryer is mantled for another set experiment. The same procedure is carried out each time with variation of parameters one at a time. Each time after the experiment is over; the entire spray dryer set-up is cleaned for the next experiment.

3.3 Data Processing

The experimental data for the outlet temperature and the weight of different salts collected after the spray drying of varying concentration have been observed with different inlet temperatures, aspirator speed, pump flow rate and atomization rate (inlet air pressure). These data have been processed to predict the output namely the outlet temperature and the % Yield by the conventional dimensional analysis method.

3.3.1 Dimensional analysis Approach

The following system variables which are likely to influence the output of the system viz.the Outlet temperature(To) and the % Yield(Y) have been considered in the development of the correlation.

Inlet Temperature (Ti)

Aspirator Speed (Uasp)

Pump flow rate (Up)

Concentration of salt(Cs)

Atomization rate (Piair)

Molecular weight of salt (Ms)

An attempt has been made to develop correlations for the Outlet temperature and the %Yield (Y) of different salts on the basis of dimensional analysis.

$$T_o = K_1\left[(T_1)^{a1}(U_{asp})^{b1}(U_p)^{c1}(C_s)^{d1}(P_{i-air})^{e1}(M_s)^{f1}\right]^{n1} \text{........(3.1)}$$

$$Y = K_2\left[(T_1)^{a2}(U_{asp})^{b2}(U_p)^{c2}(C_s)^{d2}(P_{i-air})^{e2}(M_s)^{f2}\right]^{n2} \text{.........(3.2)}$$

The values of the individual exponents (a to f) have been obtained using log-log plots of the respective dependent parameters (To and Y) against the independent parameters and fitted to the straight lines. The final correlations, the plots and the results, thus obtained for the Outlet temperature and the %Yield have been reported in chapter-4. The plots of Outlet temperature for the final values of the constants (K) and the exponents (n), the correlation plots of respective dependent parameters (To and Y) against system parameters have been drawn separately on log-log plots and fitted to straight lines by regression analysis.

For water the correlation between Outlet temperature and the independent parameters such as Inlet Temperature (Ti), Aspirator Speed (Uasp), Pump flow rate (Up) and Atomization rate (Piair) has been developed on the basis of dimensional analysis similarly as in the case of salts.

$$T'_o = K'\left[(T_1)^{a'}(U_{asp})^{b'}(U_p)^{c'}(P_{i-air})^{d'}\right]^{n'} \text{........(3.3)}$$

The values of the individual exponents (a' to d') have been obtained using log-log plots of the dependent parameters (To') against the independent parameters and fitted to the straight lines. The final correlations, the plots and the results, thus obtained for the Outlet temperature and the %Yield have been reported in chapter-4

The data tables and plots of Outlet temperature against Pump flow rate for different inlet temperatures have been shown in tables 34 to 37 and fig- 38 respectively in the appendix-1 and appendix-2.

And the data tables and plots of Outlet temperature against atomization rate for different Aspirator speed have been shown in tables 38 to 44 and fig- 39 respectively in the appendix1 and appendix-2.

The dried salts are being processed for different analysis. These are as follows:

3.4 Moisture Analysis

Moisture analysis has been performed on dried samples using an Sartorious Electronic Moisture Analyzer Model MA150 (temperature range 40 to 200^0C, weighing capacity 159 gm with minimum sample weight 0.1 gm) .All spray-dried samples have a final moisture content in the range of 0.2% to 1.5% wt/wt irrespective of the parametric conditions maintained in the spray dryer. All samples are stored in sealed vials and physical characterization has been performed within 24 to 48 hours. No change in the moisture content has been observed at the end of this storage time.

3.5 Fourier-Transform Infrared Spectroscopy (Salt Characterization)

Fourier Transform Infrared Spectroscopy provides specific information about chemical bonding and molecular structures making it useful for analyzing organic materials and certain inorganic materials. Chemical bonds vibrate at characteristic frequencies and when exposed to infrared radiation, they absorb the radiation at frequencies that match their vibration modes. Measuring the radiation absorption as a function of frequency produces a spectrum that can be used to identify functional groups and compounds. The interception of infrared spectra involves the correlation of absorption bands in the spectrum of an unknown compound with the known absorption frequencies for types of bonds.[(34)] Significant for the identification of the source of an absorption band are intensity (weak, medium or strong) shape (broad or sharp) and position (cm^{-1}) in the spectrum.

FTIR spectroscopy has been used to characterize the amorphous and crystalline polymorphs of salts like Sodium Sulfate, Sodium chloride and Mannitol. FTIR scans of dried samples have been collected on a IR-Prestige-21 FTIR spectrometer (Japan) equipped with a dTGS de-tector. For each dried sample, an amount equivalent to approximately 1.0 mg of salt has been mixed with 150 mg of dried KBr to produce the KBr pellet. A total of 6 scans were accumulated at 4-cm^{-1} instrument resolution in the re-gion of 4000 cm^{-1} to 400 cm^{-1}.

3.6 Scanning Electron Microscopy

The Scanning Electron Microscope is a type of electron microscope that images the sample surface by scanning it with a high energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity.

A beam of electrons is produced at the top of the microscope by an electron gun. The electron beam follows a vertical path through the microscope, which is held within a vacuum. The beam travels through electromagnetic fields and tenses, which focus the beam down towards the sample. Once the beam hits the sample, electron and X rays are ejected from the sample. Detectors collect these X rays, back scattered electrons and secondary electrons and convert them into a signal that is sent to a screen similar to a television screen. [32,35]This produces the final image. It has a range from 15X to 20,000X reached in 25 steps and a resolution of 5nm.
SEM images were obtained for all of the spray-dried powders to examine particle morphology. A JEOL model 6400 scanning electron microscope (JEOL 6480 LV JAPAN) was used for imaging after samples were sputter coated with Au.

All metals are conductive and require no preparation before being used. All non metals need to be made conductive by covering the sample with a thin layer of conductive materials.This is done by using a device called a "sputter Coater". The Sputter Coater uses an electric field and Argon gas. The sample is placed in a sample chamber that is at a vacuum. Argon gas and an electric field cause an electron to be removed from the argon, making the atoms positively charged. The argon ions then become attracted to a negatively charged gold foil. The argon ions knock gold atoms from the surface of the gold foil. These gold atoms fall and settle into the surface3 of the sample producing a thin gold coating.

3.7 Thermogravimetry and Differential Thermal Analysis (TGA& DTA)

Differential Thermal Analyzer (DTA) measures the temperature difference between a sample and a reference material as they are heated, cooled or held at a constant (isothermal) temperature.

Thermogravimetric Analyzer (TGA) measures the change in mass of a sample as the sample is heated, cooled or held at a constant (isothermal) temperature.

Thermo gravimetric Analysis is a type of testing that is performed on samples to determine changes in mass as a function of temperature. The TGA can be used to give thermal properties including the transition temperature, melting point, reaction temperature such as absorption and decomposition, characterize oxidation behaviour, set burning point or conditioning parameters (temperature/ ramp rate/ time) and determine chemical composition. TGA and DTA plots are obtained for all spray dried salts using a Thermogravimety and Differential Thermal Analyser (DTG-60/60 H withTA-60 WH control unit, temperature range is ambient to 1500^{0}C Shimadzu Corporation Kyoto Japan)

When the sample and the reference substance are heated at a constant rate, their temperature increases as shown in the figure. Since the reference substance is thermally inert, its temperature continues to show a stable increase. If any endothermic change (for example, fusion) has occurred in the sample, the externally applied heat energy will be consumed for that reaction and thus the temperature increase is hindered. When the change is over, the occurrence of a great temperature difference from the ambient temperature causes a large quantity of heat energy to enter the sample. This suddenly increases the temperature, brings the sample back to its original state, and then makes the temperature start increasing again at a stable rate. Now if the temperature difference between the two (DTA signal) is detected and then amplified, it can be recorded as the signal of peak. The sample temperature (furnace temperature) is measured with a thermocouple for temperature sensor.

Table-45, Feed Pump Flow Calibration

Sr No	pf in%	Flow, ml/min Rdg1	Flow, ml/min Rdg2	Flow,ml/min Rdg3	Avg. Flow, ml/min	St. Dev
1	0	0	0	0	0	0
2	1	0.30477	0.30477	0.302216	0.303919	0.001474
3	2	0.629723	0.60778	0.582902	0.606801	0.023426
4	3	0.941176	0.945577	0.853566	0.91344	0.051899
5	4	1.319358	1.215559	1.144747	1.226555	0.087823
6	5	1.518091	1.383126	1.419446	1.440221	0.069839
7	6	1.842941	1.730936	1.657917	1.743931	0.093194
8	7	2.016129	2.053154	2.00848	2.025921	0.023892
9	8	2.390756	2.255074	2.192982	2.279604	0.101143
10	9	2.54972	2.489213	2.357564	2.465499	0.098248
11	10	2.823529	2.706848	2.671892	2.73409	0.079404
12	11	3.118827	3.096295	2.910079	3.041734	0.114572
13	12	3.276182	3.267974	3.098853	3.214336	0.100095
14	13	3.611847	3.521954	3.427788	3.520529	0.092038
15	14	3.788357	3.821169	3.721623	3.77705	0.050727
16	15	4.023605	4.042582	3.891555	3.985914	0.082266
17	16	4.37254	4.472272	4.123711	4.322841	0.179516
18	17	4.589261	4.645401	4.367448	4.534037	0.146975
19	18	5.04117	5.042017	4.721435	4.934874	0.184844
20	19	5.315379	5.23195	4.8	5.115776	0.276634
21	20	5.436752	5.314438	5.196605	5.315932	0.120081
22	22	6.264356	6.224066	5.787037	6.09182	0.264717
23	24	6.793478	6.759802	6.274838	6.609373	0.290204
24	26	7.407407	7.239382	6.832157	7.159649	0.295798
25	28	8.176615	7.770008	7.327797	7.75814	0.424533
26	30	8.542141	8.130081	7.658923	8.110382	0.441939
27	32	9.118541	8.733624	8.324084	8.725417	0.397292
28	34	9.410289	9.262118	8.537279	9.069895	0.467171
29	36	10.27397	9.794319	9.360374	9.809555	0.45699
30	38	10.78361	10.70282	9.803922	10.43012	0.543803
31	40	11.34216	10.9569	10.22844	10.8425	0.565605
32	42	11.5119	11.24227	10.68376	11.14598	0.422382
33	44	11.59644	11.52295	11.13586	11.41842	0.247448
34	46	11.91422	11.76009	11.23175	11.63535	0.357926
35	48	12.13101	11.95219	11.41987	11.83436	0.369926
36	50	12.9842	12.19017	11.86709	12.34715	0.574865
37	52	12.98982	12.42751	12.32033	12.57922	0.35961
38	54	13.42582	13.05767	12.66357	13.04902	0.381199
39	56	14.88464	13.5257	13.05767	13.82267	0.949
40	58	15.06781	14.0779	13.84722	14.33097	0.648455
41	60	15.60468	14.21801	13.94376	14.58882	0.890387
42	62	16.29549	14.98501	14.66276	15.31442	0.864776
43	64	16.95235	15.77702	15.48387	16.07108	0.777147
44	66	17.01967	15.41888	15.04514	15.82789	1.048887
45	68	17.8536	16.30435	16.15219	16.77005	0.941465
46	70	18.02524	16.73485	16.52286	17.09431	0.813141
47	75	18.83239	17.50292	17.40476	17.91336	0.797421
48	80	20.25658	19.13672	18.68383	19.35904	0.809605
49	85	22.01027	20.50581	20.44061	20.98556	0.888022
50	90	23.83475	22.2662	21.8712	22.65738	1.038577
51	95	24.97225	23.3463	23.58491	23.96782	0.878007
52	100	25.86207	23.69044	23.69044	24.41432	1.253788

Table-46, Aspirator Speed Calibration

Sr No	Aspirator speed %	Vacuum in kg/cm^2 Rdg1	Vacuum in kg/cm^2 Rdg2	Vacuum in kg/cm^2 Rdg3	Avg Vacuum in kg/cm^2	St. Dev
1	0	0	0	0	0	0
2	10	0	0	0	0	0
3	20	0	0	0	0	0
4	22	0	0	0	0	0
5	24	0	0	0	0	0
6	26	0.000049	0.000039	0.000019	3.57E-05	1.53E-05
7	28	0.00099	0.000079	0.000079	0.000383	0.000526
8	30	0.00179	0.00119	0.00119	0.00139	0.000346
9	32	0.00249	0.00199	0.0019	0.002127	0.000318
10	34	0.0029	0.00219	0.00219	0.002427	0.00041
11	36	0.00379	0.00319	0.0029	0.003293	0.000454
12	38	0.00459	0.0039	0.0039	0.00413	0.000398
13	40	0.00519	0.00479	0.00439	0.00479	0.0004
14	42	0.00619	0.00579	0.00519	0.005723	0.000503
15	44	0.00699	0.00579	0.00649	0.006423	0.000603
16	46	0.0079	0.00619	0.00719	0.007093	0.000859
17	48	0.0089	0.00719	0.00829	0.008127	0.000867
18	50	0.00979	0.00819	0.0089	0.00896	0.000802
19	52	0.01079	0.00899	0.0099	0.009893	0.0009
20	54	0.01119	0.01079	0.01059	0.010857	0.000306
21	56	0.01249	0.01179	0.01169	0.01199	0.000436
22	58	0.0129	0.01259	0.01239	0.012627	0.000257
23	60	0.01339	0.0129	0.01279	0.013027	0.000319
24	62	0.01419	0.01349	0.01319	0.013623	0.000513
25	64	0.0149	0.01419	0.0139	0.01433	0.000514
26	66	0.01579	0.01519	0.01479	0.015257	0.000503
27	68	0.01679	0.0159	0.01589	0.016193	0.000517
28	70	0.01779	0.0169	0.01669	0.017127	0.000584
29	72	0.01859	0.01779	0.01759	0.01799	0.000529
30	74	0.01879	0.01779	0.01779	0.018123	0.000577
31	76	0.01949	0.01879	0.01849	0.018923	0.000513
32	78	0.02039	0.01979	0.01939	0.019857	0.000503
33	80	0.02049	0.01979	0.01949	0.019923	0.000513
34	82	0.02079	0.02039	0.0199	0.02036	0.000446
35	84	0.02079	0.02039	0.02019	0.020457	0.000306
36	86	0.02089	0.02039	0.02019	0.02049	0.000361
37	88	0.02049	0.02049	0.02019	0.02039	0.000173
38	90	0.02039	0.02049	0.0199	0.02026	0.000316
39	92	0.01979	0.01939	0.0199	0.019693	0.000268
40	94	0.01979	0.01939	0.0159	0.01836	0.00214
41	96	0.01679	0.01919	0.0159	0.017293	0.001702
42	98	0.01679	0.01919	0.0159	0.017293	0.001702
43	100	0.01679	0.01919	0.0159	0.017293	0.001702

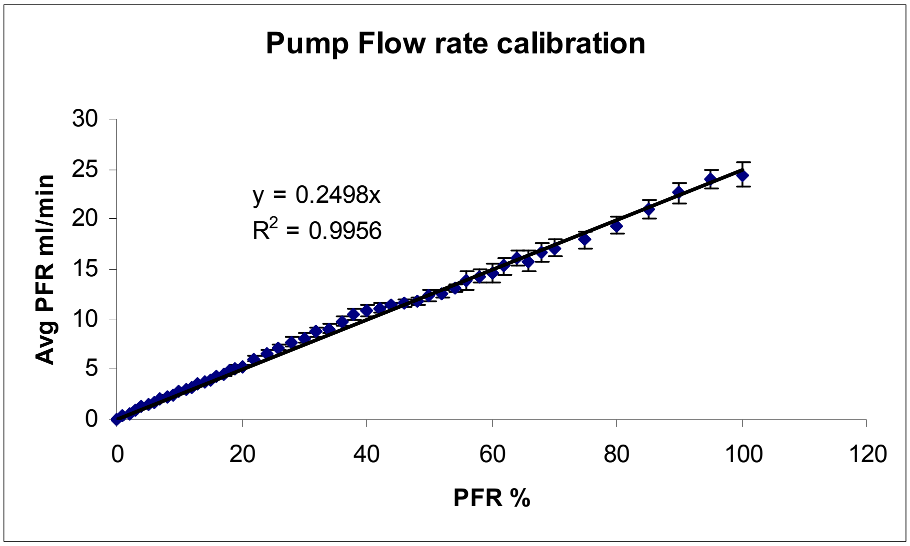


Figure-40

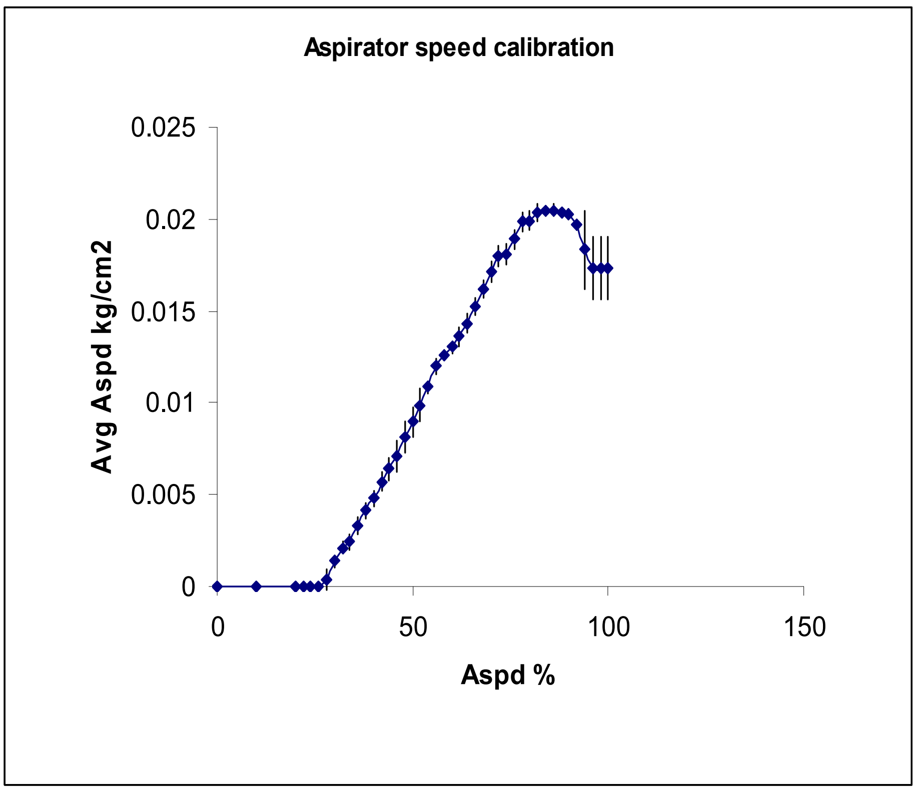


Figure-41

CHAPTER- IV

Result and Discussion

The Outlet temperature and the % Yield are calculated using the data of varying parameters and a model has been developed through dimensional analysis for the mini spray dryer, LU-20. The observed data tables and the plots for calculating the exponents of the individual parameters are given in the appendix-1 and 2 respectively. The overall calculated result for outlet temperature and the percentage yield for the developed model are shown in tables 43 to 45 and the respective model plots are shown in fig-42 to 44 at the end of this chapter.

The developed models for the outlet temperature and percentage yield for various salt solutions are as follows.

$$T_o = 2.2032\left[(T_i)^{0.079}(U_{asp})^{0.2026}(U_p)^{-0.229}(C_s)^{-0.0653}(P_{i-air})^{-0.1567}(M_s)^{0.1259}\right] \quad \ldots(4.1)$$

and

$$\mathrm{Y} = 251.09\left[(\mathrm{T_i})^{-0.1532}(\mathrm{U_{asp}})^{-0.0913}(\mathrm{U_p})^{-0.6651}(\mathrm{C_s})^{0.0659}(\mathrm{P_{i-air}})^{-0.2518}(\mathrm{M_s})^{-0.0375}\right] \quad \ldots(4.2)$$

For water the model equation is

$$T'_o = 10.874\left[(T_i)^{0.609}(U_{asp})^{0.1404}(U_p)^{-0.4364}(P_{i-air})^{-0.1748}\right] \quad \ldots.(4.3)$$

From the experiment it has been observed that outlet temperature increases with increase in inlet temperature, aspirator speed and molecular weight of salt where as it decreases with the increase in pump flow rate, concentration of salt solution and atomization rate as shown in fig-22 to 27 in the appendix-2. The outlet temperatures is observed to vary within 40°C to 90°C. In case of spray drying temperature-sensitive proteins and peptides; it is important that the outlet temperature is low to avoid product degradation.

It is observed from the experiment that the spray concentration influences the particle size. The higher the concentration of the spray solution, the larger and more porous of the dried particles. The lower the concentration of the spray solution, the smaller and finer the dried particle.

And the %Yield increases with increase in concentration of the salt solution and molecular weight of the salt whereas it decreases with the increase in inlet temperature, aspirator speed, pump flow rate and atomization rate as shown in fig-28 to 33 in the appendix-2.

It is also observed that the condensation rate in the drying chamber increases with increase in the liquid feed rate, aspirator speed and the atomization rate. Condensation inside the chamber causes a loss in yield because the dried particles stick to the chamber walls and therefore cannot be collected. Most of the sprays resulted in low yields because of the difficulties in particle collection in spray drying, particularly when trying to produce small particles. Many of the smallest particles cannot be recovered in the lab-scale apparatus because they do not efficiently deposit in the cyclone and because their low masses cause them to be drawn up into the vacuum.

The outlet temperature for water (blank solution) increases with the increase in inlet temperature and aspirator speed whereas it decreases with the increase in pump flow rate and atomization rate as shown in the fig-34 to 37in the appendix-2.

From the figure-38 it is seen that the outlet temperature initially increases with the pump flow rate and then linearly decreases. As the inlet temperature is increased simultaneously the trend remains same but the values of outlet temperature increases with increase in inlet temperature. And from figure-39 it is found that the outlet temperature decreases with increase in the atomization rate, as the Aspirator speed increases simultaneously the trend remains same but the values of the outlet temperature increases with the increase in aspirator speed.

4.1 Factorial Design: The developed correlations by factorial and fractional factorial design methods for different systems are as follows:

For salts the equations are

$$T_O = 51.96 + (-1.294)A + (-0.406)B + (-2.98)C + (-1.56)D + (2.606)E + (-1.45)F + (0.194)AB + (-2.73)AC + (-3.18)AD + (-1.84)BC + (0.256)BD + (3.58)CD + (2.08)ABD + (0.76)ACD + (0.72)ABCD$$

…..**(4.4)**

and

$$Y = 62305 + (-4.34)A + (5.14)B + (-2.08)C + (-2.99)D + (1.31)E + (-0.345)F + (-0.395)AB + (-2.56)AC + (-2.27)AD + (2.67)BC + (2.07)BD + (-1.28)CD + (-0.67)ABD + (-3.89)ACD + (0.18)ABCD$$

…..**(4.5)**

Where A =T_i, B =U_{asp}, C =U_p, D =C_s, E = (ABC) = $P_{i\text{-}air}$,F =BCD = M_s.

For water the equation is

$$T_o = 58.43 + (-0.294)A + (0.56)B + (0.64)C + (-7.018)D + (0.23)AB + (0.22)AC + (-2.17)AD + (0.57)BC + (-4.27)BD + (2.356)CD + (0.144)ABC + (0.58)ABD + (0.82)ACD + (1.17)BCD + (0.144)ABCD$$

…..**(4.6)**

Where A = T_i, B = U_{asp}, C =U_p, D = $P_{i\text{-}air}$.

The 2^4 factorial design is shown in the table-50. Table for the development of coefficients of correlation for the outlet temperature, % yield of salt solution and the outlet temperature of blank solution(water) and calculation of outlet parameters are shown in table-51 to table-56

4.2 Analysis of ANN: Computation through neural network is one of the recently growing areas of artificial intelligence. Neural networks are promising due to their ability to learn highly nonlinear relationship. An artificial neural network based model has been defined in literature as a computing system made up of a number of simple, highly interconnected processing elements which processes information by its dynamic state response to external inputs. The back propagation network which is the most well known and widely used among the current types of neural network system has been used in the present study. A three layered feed forward Neural Network is considered for this problem. The network is trained for a given set of input and target data sets These sets are obtained from the experimental observations. The network is trained with a certain number of data sets for blank solution and salt solution. For water (blank solution) each set consists of four system parameters and the corresponding experimental value of the outlet temperature, where for salt solution each set consists of six system parameters and the corresponding experimental value of the outlet temperature and the yield. The data were scaled down or normalized and then the network was exposed to these scaled/normalized data sets. The different dependent and independent were normalized/scaled down so as to lie in the same range group of 0-1(zero to one).The weights obtained through the network learning for different systems are listed in Appendix-1.

For the proper training of the input-output data, the number of neurons in the hidden layer of the ANN-structure was decided on the basis of the last error criterion. For this, tests were conducted for different ANN-structures for fixed epochs (cycles) and constant learning rate and other ANN-parameters viz. error tolerance, momentum parameter, noise factor and the slope parameter. In each test the error obtained was noted and a structure with last error was selected for rigorous training of the system. The learning rate was varied in the range of 0.001 to 1.0 during the training of the input-output data. The number of cycles selected during the training was so high that the ANN-process could be rigorously trained. The optimum ANN-structures are shown in figure-77 to figure-79. The parameters of the optimum ANN- structure for both salt solution and blank solution are listed in tables in Appendix-1.The training of the network using input and output data for a particular set of values resulted in a system which can be conveniently used as a tool for the prediction of the output. In the present investigation ANN-processing for different sets have been carried out and their predictions have been used to compare with the results obtained through the corresponding dimensional analysis and factorial designs. The comparison of the outlet parameters obtained through different analysis is shown in the table- 64 to table-66.

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4.3 Moisture Analysis

All spray-dried samples have a final moisture content in the range of 0.2% to 1.5% wt/wt irrespective of the parametric conditions maintained in the spray dryer.

4.4 Scanning Electron Microscope Report

The morphologies of the different spray-dried powders have been examined by SEM. Various particle morphologies were observed, including (I) smooth spheres, (II) collapsed or dimpled particles, (III) particles with a “raisin-like” appearance, and (IV) highly crumpled, folded structures. Examples of these can be seen in the SEM images shown in Fig- 45 to 66. in the appendix-2.

The particle morphology plays a profound role in the aerodynamic properties and performance of aerosol applications. For instance, having a porous, “crumpled” structure results in a much lower aerodynamic particle diameter compared with a dense particle. Therefore when the water in the droplet evaporates, a smaller particle remains. and when the atomization air flow rate is high, the drop exiting the nozzle tends to be smaller, so the resulting dried particle will be smaller.

4.5 FTIR Studies

It has been shown in the fig-67 to 72 in the appendix-2 that the FTIR spectra of the 6 polymorphs of salts differ considerably and reflect the difference in the interaction forces between molecules that result from different conformation arrangements in each crystal polymorph. By similar argument, considerable changes in the FTIR spectra should also be observed be-tween the amorphous form and the crystalline forms of the same material. In general, the peaks observed in a typical FTIR spectrum can be categorized in 2 sections: (1)

the "functional group" region from 4000 to 2000 cm^{-1}, in which the peaks are characteristic of specific kinds of bonds and their vibrational modes, and (2) the "fingerprint" region from 2000 to 400 cm^{-1}, where the peaks arise from complex deformations of the whole molecule. The peaks in the fin-gerprint region are a characteristic of molecular symmetry or combination bands arising from multiple bonds deform-ing simultaneously and hence are unique to each molecule. In the present FTIR studies, the region of 4000 to 2000cm^{-1} was evaluated in order to gain an understanding of the physical state of salts in various dried samples. Figure-67 shows the FTIR spectra of pure NaCl, that shows some sharp peaks between 4000 and 3250cm^{-1} and one sharp peak between 2400 and 2200cm^{-1},whereas Figure68 shows the FTIR spectra of spray dried NaCl having one sharp peak between 3700 and 2950$cm^{-1}$and another sharp peak between2400 and 2200cm^{-1}. Figure 69 shows the FTIR spectra of pure mannitol, and Figure 70 shows the FTIR spectra of spray dried Mannitol As observed, pure mannitol showed sharp peaks between 3400 cm^{-1} and 3200 cm^{-1} that are characteris-tic of the O-H stretching vibrations with intermolecular H-bonds. Another set of sharp peaks was observed between 3000 and 2800 cm^{-1}, characteristic of the C-H stretching vibrations. Some small peaks are observed between 2800 and 2200 cm^{-1}. It is observed that the FTIR spectrum of spray dried pure Mannitol is almost same as that of pure Mannitol.Figure71 shows the FTIR spectra of pure Na_2SO_4 having only one sharp peak between 2200 and 2100cm^{-1} whereas figure 72 shows the FTIR report of spray dried Na_2SO_4 with one broad peak between 3500 and 3450cm^{-1} and one sharp peak between 2200 and 2100cm^{-1}.

The fingerprint region (2000-400 cm^{-1}) actually provided a better indicator of the physical state of salts. This finding is useful as any change in the spec-trum shape could be related directly to a change in the physical state of the salts. The overall absence of sharp peaks in the fingerprint region, re-sulting in broadening of the spectrum, is a direct indication of salt being present in the amorphous form, The loss of peaks occurs because of a loss in the specific vibrational modes of the salt molecule, which are re-stricted in a crystal, to the much more widely distributed vibrational modes that are typical of an amorphous system.

4.6 Thermogravimetry and Differential Thermal Analysis Report

The figures73 to 76 in the appendix-2 show the TGA and DTA report of the spray dried salts.TGA shows the mass/time(mg/min) for the sample, whereas DTA shows the difference in temperature of sample and the reference substance in terms of μV/min. The hold up temperature is taken 105^0C.From the plot it is found that the moisture content of the spray dried salt is very less ranging from 0.6to1.5%

Table-47, Comparison of the calculated outlet temperature with the experimental outlet temperature for salt solution by dimensional analysis

SrNo	Ti °C	Uasp, kg/cm2	Up, ml/min	Cs gm /ml	Piair kg/cm2	Ms	Product Of system parameters	exp.To °C	cal. To °C	%dev.
1	120	0.00478	2.279604	0.1	2.10919	132.13	22.41139	51.2	51.927	-1.421
2	140	0.00478	2.279604	0.1	2.10919	132.13	25.26542	60.7	58.65	3.3698
3	160	0.00478	2.279604	0.1	2.10919	132.13	28.02987	68.2	65.181	4.4254
4	180	0.00478	2.279604	0.1	2.10919	132.13	30.71831	69.5	71.539	-2.934
5	120	0.00923	2.279604	0.1	2.10919	132.13	25.5536	58.2	59.334	-1.949
6	120	0.013	2.279604	0.1	2.10919	132.13	27.35969	61.4	63.598	-3.580
7	120	0.017	2.279604	0.1	2.10919	132.13	28.86306	66.5	67.151	-0.979
8	120	0.00478	3.214336	0.1	2.10919	132.13	20.74111	49.6	47.997	3.2308
9	120	0.00478	3.985914	0.1	2.10919	132.13	19.75929	46.4	45.689	1.5311
10	120	0.00478	5.315932	0.1	2.10919	132.13	18.5176	42.4	42.773	-0.880
11	120	0.00478	2.279604	0.2	2.10919	132.13	21.43446	47.5	49.628	-4.480
12	120	0.00478	2.279604	0.3	2.10919	132.13	20.88286	44.3	48.330	-9.098
13	120	0.00478	2.279604	0.4	2.10919	132.13	20.50012	48.4	47.430	2.0024
14	120	0.00478	2.279604	0.1	2.8122	132.13	21.43838	48.1	49.637	-3.196
15	120	0.00478	2.279604	0.1	3.51532	132.13	20.71273	45.2	47.930	-6.041
16	120	0.00478	2.279604	0.1	4.2183	132.13	20.13822	46.7	46.580	0.2567
17	120	0.00478	2.279604	0.1	2.10919	142.04	22.61311	56.5	52.402	7.2515
18	120	0.00478	2.279604	0.1	2.10919	58.54	20.26115	49.4	46.869	5.1234
19	120	0.00478	2.279604	0.1	2.10919	182.17	23.32114	57.2	54.070	5.4709

Table-48, Comparison of calculated %yield with experimental %yield by dimensional analysis for salt solution.

Sr. No	Ti , °C	Uasp, kg/cm^2	Up, ml/min	Cs, gm/ml	Pi-air, kg/cm2	Ms	Product Of system parameters	exp. %Yield	Cal %Yield	%dev.
1	120	0.00478	2.2796	0.1	2.10919	132.13	0.19812	68.6	67.268	0.0194
2	140	0.00478	2.2796	0.1	2.10919	132.13	0.192449	65.8	65.697	0.0015
3	160	0.00478	2.2796	0.1	2.10919	132.13	0.187668	64.5	64.366	0.0020
4	180	0.00478	2.2796	0.1	2.10919	132.13	0.183549	63.5	63.214	0.0044
5	120	0.00923	2.2796	0.1	2.10919	132.13	0.184008	70.4	63.343	0.1002
6	120	0.013	2.2796	0.1	2.10919	132.13	0.177065	61.9	61.391	0.0082
7	120	0.017	2.2796	0.1	2.10919	132.13	0.17181	59.9	59.905	-8.8E-05
8	120	0.00478	3.2143	0.1	2.10919	132.13	0.1496	60.54	53.524	0.1158
9	120	0.00478	3.9859	0.1	2.10919	132.13	0.125472	56.27	46.388	0.1756
10	120	0.00478	5.3159	0.1	2.10919	132.13	0.099156	32.9	38.303	-0.164
11	120	0.00478	2.2796	0.2	2.10919	132.13	0.209576	69.9	70.416	-0.007
12	120	0.00478	2.2796	0.3	2.10919	132.13	0.216582	71.26	72.325	-0.014
13	120	0.00478	2.2796	0.4	2.10919	132.13	0.221695	78.14	73.711	0.0566
14	120	0.00478	2.2796	0.1	2.8122	132.13	0.181243	55.4	62.567	-0.129
15	120	0.00478	2.2796	0.1	3.51532	132.13	0.169148	60.2	59.148	0.0174
16	120	0.00478	2.2796	0.1	4.2183	132.13	0.159868	52.83	56.495	-0.069
17	120	0.00478	2.2796	0.1	2.10919	142.04	0.197459	70.29	67.085	0.0455
18	120	0.00478	2.2796	0.1	2.10919	58.54	0.205713	64.85	69.358	-0.069
19	120	0.00478	2.2796	0.1	2.10919	182.17	0.195202	57.18	66.461	-0.162

Table-49: Comparison of calculated outlet temperature with the experimental outlet temperature by dimensional analysis for blank solution(water)

Sr no	Ti ^oC	Uasp, kg/cm2	Up, ml/min	Piair kg/cm2	Product Of system parameters	exp. To ^oC	cal.. To ^oC	%dev.
1	120	0.00478	2.279604	2.10919	5.217432	58.4	58.0618	0.5791
2	140	0.00478	2.279604	2.10919	5.723544	65.1	63.77664	2.0328
3	160	0.00478	2.279604	2.10919	6.201475	71	69.17979	2.5636
4	180	0.00478	2.279604	2.10919	6.656059	74.2	74.32443	-0.1676
5	120	0.00478	2.279604	2.10919	5.217432	58.4	58.0618	0.5791
6	120	0.00923	2.279604	2.10919	5.715266	60.6	63.68311	-5.0876
7	120	0.013	2.279604	2.10919	5.992902	66.5	66.82107	-0.4828
8	120	0.017	2.279604	2.10919	6.219754	69.4	69.38656	0.0193
9	120	0.00478	2.279604	2.10919	5.217432	58.4	58.0618	0.5791
10	120	0.00478	3.214336	2.10919	4.500154	49.3	49.97605	-1.3712
11	120	0.00478	3.985914	2.10919	4.102157	45.4	45.4971	-0.2138
12	120	0.00478	5.315932	2.10919	3.624016	40.5	40.12436	0.9275
13	120	0.00478	2.279604	2.10919	5.217432	58.4	58.0618	0.5791
14	120	0.00478	2.279604	2.8122	4.964994	54.4	55.21422	-1.4967
15	120	0.00478	2.279604	3.51532	4.777602	53.3	53.10168	0.3720
16	120	0.00478	2.279604	4.2183	4.629783	51.6	51.43607	0.3176

$2^{6-2} = 2^4$ Factorial Design

Table-50

Treat-ment com-bination	Level of factor				Interactions										
	A	B	C	D	AB	AC	AD	BC	BD	CD	E=ABC	ABD	ACD	F=BCD	ABCD
I	-	-	-	-	+	+	+	+	+	+	-	-	-	-	+
a	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-
b	-	+	-	-	-	+	+	-	-	+	+	+	-	+	-
ab	+	+	-	-	+	-	-	-	-	+	-	-	+	+	+
c	-	-	+	-	+	-	+	-	+	-	+	-	+	+	-
ac	+	-	+	-	-	+	-	-	+	-	-	+	-	+	+
bc	-	+	+	-	-	-	+	+	-	-	-	+	+	-	+
abc	+	+	+	-	+	+	-	+	-	-	+	-	-	-	-
d	-	-	-	+	+	+	-	+	-	-	-	+	+	+	-
ad	+	-	-	+	-	-	+	+	-	-	+	-	-	+	+
bd	-	+	-	+	-	+	-	-	+	-	+	-	+	-	+
abd	+	+	-	+	+	-	+	-	+	-	-	+	-	-	-
cd	-	-	+	+	+	-	-	-	-	+	+	+	-	-	+
acd	+	-	+	+	-	+	+	-	-	+	-	-	+	-	-
bcd	-	+	+	+	-	-	-	+	+	+	-	-	-	+	-
abcd	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+

Table-51-Development of coefficients of correlation for the outlet temperature of salt solution.

A	B	C	D	E	F	
Ti	Uasp	Up	Cs	Piair	Ms	To Exp
120	0.00478	2.279604	0.1	2.10919	58.54	51.2
180	0.00478	2.279604	0.1	4.2183	58.54	69.5
120	0.017	2.279604	0.1	4.2183	182.17	58.2
180	0.017	2.279604	0.1	2.10919	182.17	61.4
120	0.00478	5.315932	0.1	4.2183	182.17	49.6
180	0.00478	5.315932	0.1	2.10919	182.17	46.4
120	0.017	5.315932	0.1	2.10919	58.54	47.5
180	0.017	5.315932	0.1	4.2183	58.54	44.3
120	0.00478	2.279604	0.4	2.10919	182.17	48.1
180	0.00478	2.279604	0.4	4.2183	182.17	45.2
120	0.017	2.279604	0.4	4.2183	58.54	56.5
180	0.017	2.279604	0.4	2.10919	58.54	49.4
120	0.00478	5.315932	0.4	4.2183	58.54	66.5
180	0.00478	5.315932	0.4	2.10919	58.54	42.4
120	0.017	5.315932	0.4	2.10919	182.17	48.4
180	0.017	5.315932	0.4	4.2183	182.17	46.7

Contd. Table-51

To Exp	a1	a2	a3	a4	a5	a6	a12
51.2	-51.2	-51.2	-51.2	-51.2	-51.2	-51.2	51.2
69.5	69.5	-69.5	-69.5	-69.5	69.5	-69.5	-69.5
58.2	-58.2	58.2	-58.2	-58.2	58.2	58.2	-58.2
61.4	61.4	61.4	-61.4	-61.4	-61.4	61.4	61.4
49.6	-49.6	-49.6	49.6	-49.6	49.6	49.6	49.6
46.4	46.4	-46.4	46.4	-46.4	-46.4	46.4	-46.4
47.5	-47.5	47.5	47.5	-47.5	-47.5	-47.5	-47.5
44.3	44.3	44.3	44.3	-44.3	44.3	-44.3	44.3
48.1	-48.1	-48.1	-48.1	48.1	-48.1	48.1	48.1
45.2	45.2	-45.2	-45.2	45.2	45.2	45.2	-45.2
56.5	-56.5	56.5	-56.5	56.5	56.5	-56.5	-56.5
49.4	49.4	49.4	-49.4	49.4	-49.4	-49.4	49.4
66.5	-66.5	-66.5	66.5	66.5	66.5	-66.5	66.5
42.4	42.4	-42.4	42.4	42.4	-42.4	-42.4	-42.4
48.4	-48.4	48.4	48.4	48.4	-48.4	48.4	-48.4
46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7
ao= 51.95	a1=-1.294	a2=-0.406	a3 = -2.98	a4 = -1.56	a5=2.61	a6 = -1.46	a12=0.194

Contd. Table-51

a13	a14	a23	a24	a34	a124	a134	a1234
51.2	51.2	51.2	51.2	51.2	-51.2	-51.2	51.2
-69.5	-69.5	69.5	69.5	69.5	69.5	69.5	-69.5
58.2	58.2	-58.2	-58.2	58.2	58.2	-58.2	-58.2
-61.4	-61.4	-61.4	-61.4	61.4	-61.4	61.4	61.4
-49.6	49.6	-49.6	49.6	-49.6	-49.6	49.6	-49.6
46.4	-46.4	-46.4	46.4	-46.4	46.4	-46.4	46.4
-47.5	47.5	47.5	-47.5	-47.5	47.5	47.5	47.5
44.3	-44.3	44.3	-44.3	-44.3	-44.3	-44.3	-44.3
48.1	-48.1	48.1	-48.1	-48.1	48.1	48.1	-48.1
-45.2	45.2	45.2	-45.2	-45.2	-45.2	-45.2	45.2
56.5	-56.5	-56.5	56.5	-56.5	-56.5	56.5	56.5
-49.4	49.4	-49.4	49.4	-49.4	49.4	-49.4	-49.4
-66.5	-66.5	-66.5	-66.5	66.5	66.5	-66.5	66.5
42.4	42.4	-42.4	-42.4	42.4	-42.4	42.4	-42.4
-48.4	-48.4	48.4	48.4	48.4	-48.4	-48.4	-48.4
46.7	46.7	46.7	46.7	46.7	46.7	46.7	46.7
a13 = -2.73	a14 = -3.18	a23 = -1.84	a24 = 0.26	a34 = 3.58	a124 = 2.08	a134 = 0.75	a1234 = 0.72

Table-52 Calculation of outlet temperature of salt solution by fractional factorial design

Ti	Uasp	Up	Cs	Piair	Ms	To Exp	A eff	Beff	Ceff	Deff
120	0.00478	2.279604	0.1	2.10919	58.54	51.2	-1	-1	-1	-1
180	0.00478	2.279604	0.1	4.2183	58.54	69.5	1	-1	-1	-1
120	0.017	2.279604	0.1	4.2183	182.17	58.2	-1	1	-1	-1
180	0.017	2.279604	0.1	2.10919	182.17	61.4	1	1	-1	-1
120	0.00478	5.315932	0.1	4.2183	182.17	49.6	-1	-1	1	-1
180	0.00478	5.315932	0.1	2.10919	182.17	46.4	1	-1	1	-1
120	0.017	5.315932	0.1	2.10919	58.54	47.5	-1	1	1	-1
180	0.017	5.315932	0.1	4.2183	58.54	44.3	1	1	1	-1
120	0.00478	2.279604	0.4	2.10919	182.17	48.1	-1	-1	-1	1
180	0.00478	2.279604	0.4	4.2183	182.17	45.2	1	-1	-1	1
120	0.017	2.279604	0.4	4.2183	58.54	56.5	-1	1	-1	1
180	0.017	2.279604	0.4	2.10919	58.54	49.4	1	1	-1	1
120	0.00478	5.315932	0.4	4.2183	58.54	66.5	-1	-1	1	1
180	0.00478	5.315932	0.4	2.10919	58.54	42.4	1	-1	1	1
120	0.017	5.315932	0.4	2.10919	182.17	48.4	-1	1	1	1
180	0.017	5.315932	0.4	4.2183	182.17	46.7	1	1	1	1
140	0.00478	2.279604	0.1	2.10919	132.13	60.7	-0.33333	-1	-1	-1
160	0.00478	2.279604	0.1	2.10919	132.13	68.2	0.333333	-1	-1	-1
120	0.00478	2.279604	0.1	2.10919	58.54	49.4	-1	-1	-1	-1
120	0.00478	2.279604	0.1	2.10919	182.17	57.2	-1	-1	-1	-1

Contd.table-52

Eeff	Feff	AB eff	AC eff	AD eff	BC eff	BD eff	CDeff	ABD eff	ACD eff	ABCDeff	To cal	%Dev
-1	-1	1	1	1	1	1	1	-1	-1	1	51.2	0
1	-1	-1	-1	-1	1	1	1	1	1	-1	69.504	-0.00576
1	1	-1	1	1	-1	-1	1	1	-1	-1	58.2	0
-1	1	1	-1	-1	-1	-1	1	-1	1	1	61.416	-0.02606
1	1	1	-1	1	-1	1	-1	-1	1	-1	49.612	-0.02419
-1	1	-1	1	-1	-1	1	-1	1	-1	1	46.412	-0.02586
-1	-1	-1	-1	1	1	-1	-1	1	1	1	47.508	-0.01684
1	-1	1	1	-1	1	-1	-1	-1	-1	-1	44.308	-0.01806
-1	1	1	1	-1	1	-1	-1	1	1	-1	48.108	-0.01663
1	1	-1	-1	1	1	-1	-1	-1	-1	1	45.212	-0.02655
1	-1	-1	1	-1	-1	1	-1	-1	1	1	56.492	0.014159
-1	-1	1	-1	1	-1	1	-1	1	-1	-1	49.388	0.024291
1	-1	1	-1	-1	-1	-1	1	1	-1	1	66.48	0.030075
-1	-1	-1	1	1	-1	-1	1	-1	1	-1	42.4	-1.7E-14
-1	1	-1	-1	-1	1	1	1	-1	-1	-1	48.4	1.47E-14
1	1	1	1	1	1	1	1	1	1	1	46.72	-0.04283
-1	0.19	0.333	0.333	0.333	1	1	1	-0.33	-0.33	0.333	53.83	11.30512
-1	0.19	-0.33	-0.333	-0.333	1	1	1	0.333	0.333	-0.333	58.20	14.66013
-1	-1	1	1	1	1	1	1	-1	-1	1	51.2	-3.64372
-1	1	1	1	1	1	1	1	-1	-1	1	48.3	15.55944

Table-53 : **Development of coefficients of correlation for the %Yield of salt solution.**

A	B	C	D	E	F	
Ti	Uasp	Up	Cs	Piair	Ms	Yexp
120	0.00478	2.279604	0.1	2.10919	58.54	68.6
180	0.00478	2.279604	0.1	4.2183	58.54	63.5
120	0.017	2.279604	0.1	4.2183	182.17	70.4
180	0.017	2.279604	0.1	2.10919	182.17	61.9
120	0.00478	5.315932	0.1	4.2183	182.17	60.54
180	0.00478	5.315932	0.1	2.10919	182.17	56.27
120	0.017	5.315932	0.1	2.10919	58.54	69.9
180	0.017	5.315932	0.1	4.2183	58.54	71.26
120	0.00478	2.279604	0.4	2.10919	182.17	55.4
180	0.00478	2.279604	0.4	4.2183	182.17	60.2
120	0.017	2.279604	0.4	4.2183	58.54	70.29
180	0.017	2.279604	0.4	2.10919	58.54	64.85
120	0.00478	5.315932	0.4	4.2183	58.54	59.9
180	0.00478	5.315932	0.4	2.10919	58.54	32.9
120	0.017	5.315932	0.4	2.10919	182.17	78.14
180	0.017	5.315932	0.4	4.2183	182.17	52.83

Contd.table-53

Yexp	a1	a2	a3	a4	a5	a6	a12
68.6	-68.6	-68.6	-68.6	-68.6	-68.6	-68.6	68.6
63.5	63.5	-63.5	-63.5	-63.5	63.5	-63.5	-63.5
70.4	-70.4	70.4	-70.4	-70.4	70.4	70.4	-70.4
61.9	61.9	61.9	-61.9	-61.9	-61.9	61.9	61.9
60.54	-60.54	-60.54	60.54	-60.54	60.54	60.54	60.54
56.27	56.27	-56.27	56.27	-56.27	-56.27	56.27	-56.27
69.9	-69.9	69.9	69.9	-69.9	-69.9	-69.9	-69.9
71.26	71.26	71.26	71.26	-71.26	71.26	-71.26	71.26
55.4	-55.4	-55.4	-55.4	55.4	-55.4	55.4	55.4
60.2	60.2	-60.2	-60.2	60.2	60.2	60.2	-60.2
70.29	-70.29	70.29	-70.29	70.29	70.29	-70.29	-70.29
64.85	64.85	64.85	-64.85	64.85	-64.85	-64.85	64.85
59.9	-59.9	-59.9	59.9	59.9	59.9	-59.9	59.9
32.9	32.9	-32.9	32.9	32.9	-32.9	-32.9	-32.9
78.14	-78.14	78.14	78.14	78.14	-78.14	78.14	-78.14
52.83	52.83	52.83	52.83	52.83	52.83	52.83	52.83
a0=62.305	a1= -4.34	a2=5.14	a3= -2.08	a4=-2.99	a5=1.31	a6=-0.34	a12=-0.39

Contd.table-53

a13	a14	a23	a24	a34	a124	a134
68.6	68.6	68.6	68.6	68.6	-68.6	-68.6
-63.5	-63.5	63.5	63.5	63.5	63.5	63.5
70.4	70.4	-70.4	-70.4	70.4	70.4	-70.4
-61.9	-61.9	-61.9	-61.9	61.9	-61.9	61.9
-60.54	60.54	-60.54	60.54	-60.54	-60.54	60.54
56.27	-56.27	-56.27	56.27	-56.27	56.27	-56.27
-69.9	69.9	69.9	-69.9	-69.9	69.9	69.9
71.26	-71.26	71.26	-71.26	-71.26	-71.26	-71.26
55.4	-55.4	55.4	-55.4	-55.4	55.4	55.4
-60.2	60.2	60.2	-60.2	-60.2	-60.2	-60.2
70.29	-70.29	-70.29	70.29	-70.29	-70.29	70.29
-64.85	64.85	-64.85	64.85	-64.85	64.85	-64.85
-59.9	-59.9	-59.9	-59.9	59.9	59.9	-59.9
32.9	32.9	-32.9	-32.9	32.9	-32.9	32.9
-78.14	-78.14	78.14	78.14	78.14	-78.14	-78.14
52.83	52.83	52.83	52.83	52.83	52.83	52.83
a13=-2.56	a14=-2.27	a23=2.67	a24=2.07	a34=-1.28	a124=-0.67	a134=-3.89

Table-54: **Calculation of %Yield of salt solution by fractional factorial design**.

Ti	Uasp	Up	Cs	Piair	Ms	Yexp	A eff	Beff	Ceff	Deff
120	0.00478	2.279604	0.1	2.10919	58.54	68.6	-1	-1	-1	-1
180	0.00478	2.279604	0.1	4.2183	58.54	63.5	1	-1	-1	-1
120	0.017	2.279604	0.1	4.2183	182.17	70.4	-1	1	-1	-1
180	0.017	2.279604	0.1	2.10919	182.17	61.9	1	1	-1	-1
120	0.00478	5.315932	0.1	4.2183	182.17	60.54	-1	-1	1	-1
180	0.00478	5.315932	0.1	2.10919	182.17	56.27	1	-1	1	-1
120	0.017	5.315932	0.1	2.10919	58.54	69.9	-1	1	1	-1
180	0.017	5.315932	0.1	4.2183	58.54	71.26	1	1	1	-1
120	0.00478	2.279604	0.4	2.10919	182.17	55.4	-1	-1	-1	1
180	0.00478	2.279604	0.4	4.2183	182.17	60.2	1	-1	-1	1
120	0.017	2.279604	0.4	4.2183	58.54	70.29	-1	1	-1	1
180	0.017	2.279604	0.4	2.10919	58.54	64.85	1	1	-1	1
120	0.00478	5.315932	0.4	4.2183	58.54	59.9	-1	-1	1	1
180	0.00478	5.315932	0.4	2.10919	58.54	32.9	1	-1	1	1
120	0.017	5.315932	0.4	2.10919	182.17	78.14	-1	1	1	1
180	0.017	5.315932	0.4	4.2183	182.17	52.83	1	1	1	1
140	0.00478	2.2796	0.1	2.10919	132.13	65.8	-0.33	-1	-1	-1
160	0.00478	2.2796	0.1	2.10919	132.13	64.5	0.333	-1	-1	-1
120	0.00478	2.2796	0.1	2.10919	182.17	57.18	-1	-1	-1	-1

Contd.table-54

Eeff	Feff	AB eff	AC eff	AD eff	BC eff	BD eff	CDeff	ABD eff	ACD eff	ABCDeff	Ycal	%Dev
-1	-1	1	1	1	1	1	1	-1	-1	1	68.594	0.008746
1	-1	-1	-1	-1	1	1	1	1	1	-1	63.5015	-0.00236
1	1	-1	1	1	-1	-1	1	1	-1	-1	70.416	-0.02273
-1	1	1	-1	-1	-1	-1	1	-1	1	1	61.9035	-0.00565
1	1	1	-1	1	-1	1	-1	-1	1	-1	60.549	-0.01487
-1	1	-1	1	-1	-1	1	-1	1	-1	1	56.2565	0.023991
-1	-1	-1	-1	1	1	-1	-1	1	1	1	69.911	-0.01574
1	-1	1	1	-1	1	-1	-1	-1	-1	-1	71.2385	0.030171
-1	1	1	1	-1	1	-1	-1	1	1	-1	55.4015	-0.00271
1	1	-1	-1	1	1	-1	-1	-1	-1	1	60.189	0.018272
1	-1	-1	1	-1	-1	1	-1	-1	1	1	70.2835	0.009247
-1	-1	1	-1	1	-1	1	-1	1	-1	-1	64.851	-0.00154
1	-1	1	-1	-1	-1	-1	1	1	-1	1	59.8965	0.005843
-1	-1	-1	1	1	-1	-1	1	-1	1	-1	32.924	-0.07295
-1	1	-1	-1	-1	1	1	1	-1	-1	-1	78.1185	0.027515
1	1	1	1	1	1	1	1	1	1	1	52.846	-0.03029
-1	0.19	0.333	0.333	0.333	1.	1	1.	-0.33	-0.33	0.333	65.61246	0.285017
-1	0.19	-0.33	-0.33	-0.33	1.	1	1	0.333	0.333	-0.333	63.04162	2.26105
-1	1	1	1	1	1	1	1	-1	-1	1	67.90401	-18.7548

Table-55: Development of coefficients of correlation for the outlet temperature of blank solution(water).

A	B	C	D			
Ti	Uasp	Up	Piair	To exp	a1	a2
120	0.00478	2.279604	2.10919	58.4	-58.4	-58.4
180	0.00478	2.279604	2.10919	65.1	65.1	-65.1
120	0.017	2.279604	2.10919	71	-71	71
180	0.017	2.279604	2.10919	74.2	74.2	74.2
120	0.00478	5.315932	2.10919	58.4	-58.4	-58.4
180	0.00478	5.315932	2.10919	60.6	60.6	-60.6
120	0.017	5.315932	2.10919	66.5	-66.5	66.5
180	0.017	5.315932	2.10919	69.4	69.4	69.4
120	0.00478	2.279604	4.2183	58.4	-58.4	-58.4
180	0.00478	2.279604	4.2183	49.3	49.3	-49.3
120	0.017	2.279604	4.2183	45.4	-45.4	45.4
180	0.017	2.279604	4.2183	40.5	40.5	40.5
120	0.00478	5.315932	4.2183	58.4	-58.4	-58.4
180	0.00478	5.315932	4.2183	54.4	54.4	-54.4
120	0.017	5.315932	4.2183	53.3	-53.3	53.3
180	0.017	5.315932	4.2183	51.6	51.6	51.6
				a0=58.43	a1=-0.294	a3=0.56

Contd.table-55

a3	a4	a12	a13	a14	a23	a24
-58.4	-58.4	58.4	58.4	58.4	58.4	58.4
-65.1	-65.1	-65.1	-65.1	-65.1	65.1	65.1
-71	-71	-71	71	71	-71	-71
-74.2	-74.2	74.2	-74.2	-74.2	-74.2	-74.2
58.4	-58.4	58.4	-58.4	58.4	-58.4	58.4
60.6	-60.6	-60.6	60.6	-60.6	-60.6	60.6
66.5	-66.5	-66.5	-66.5	66.5	66.5	-66.5
69.4	-69.4	69.4	69.4	-69.4	69.4	-69.4
-58.4	58.4	58.4	58.4	-58.4	58.4	-58.4
-49.3	49.3	-49.3	-49.3	49.3	49.3	-49.3
-45.4	45.4	-45.4	45.4	-45.4	-45.4	45.4
-40.5	40.5	40.5	-40.5	40.5	-40.5	40.5
58.4	58.4	58.4	-58.4	-58.4	-58.4	-58.4
54.4	54.4	-54.4	54.4	54.4	-54.4	-54.4
53.3	53.3	-53.3	-53.3	-53.3	53.3	53.3
51.6	51.6	51.6	51.6	51.6	51.6	51.6
a3=0.64	a4=-7.018	a12=0.231	a13=0.21875	a14=-2.168	a23=0.568	a24=-4.268

Contd.table-55

a34	a123	a124	a134	a234	a1234
58.4	-58.4	-58.4	-58.4	-58.4	-58.4
65.1	65.1	65.1	65.1	-65.1	65.1
71	71	71	-71	71	71
74.2	-74.2	-74.2	74.2	74.2	-74.2
-58.4	58.4	-58.4	58.4	58.4	58.4
-60.6	-60.6	60.6	-60.6	60.6	-60.6
-66.5	-66.5	66.5	66.5	-66.5	-66.5
-69.4	69.4	-69.4	-69.4	-69.4	69.4
-58.4	-58.4	58.4	58.4	58.4	-58.4
-49.3	49.3	-49.3	-49.3	49.3	49.3
-45.6	45.4	-45.4	45.4	-45.4	45.4
-40.5	-40.5	40.5	-40.5	-40.5	-40.5
58.4	58.4	58.4	-58.4	-58.4	58.4
54.4	-54.4	-54.4	54.4	-54.4	-54.4
53.3	-53.3	-53.3	-53.3	53.3	-53.3
51.6	51.6	51.6	51.6	51.6	51.6
a34=2.356	a123=0.143	a124=0.58	a134=0.818	a234=1.168	a1234=0.144

Table-56 Calculation of outlet temperature of blank solution(water) by factorial design

Ti	Uasp	Up	Piair	To exp	A eff	Beff	Ceff
120	0.00478	2.279604	2.10919	58.4	-1	-1	-1
180	0.00478	2.279604	2.10919	65.1	1	-1	-1
120	0.017	2.279604	2.10919	71	-1	1	-1
180	0.017	2.279604	2.10919	74.2	1	1	-1
120	0.00478	5.315932	2.10919	58.4	-1	-1	1
180	0.00478	5.315932	2.10919	60.6	1	-1	1
120	0.017	5.315932	2.10919	66.5	-1	1	1
180	0.017	5.315932	2.10919	69.4	1	1	1
120	0.00478	2.279604	4.2183	58.4	-1	-1	-1
180	0.00478	2.279604	4.2183	49.3	1	-1	-1
120	0.017	2.279604	4.2183	45.4	-1	1	-1
180	0.017	2.279604	4.2183	40.5	1	1	-1
120	0.00478	5.315932	4.2183	58.4	-1	-1	1
180	0.00478	5.315932	4.2183	54.4	1	-1	1
120	0.017	5.315932	4.2183	53.3	-1	1	1
180	0.017	5.315932	4.2183	51.6	1	1	1
120	0.00478	2.10919	2.27604	58.6	-1	-1	-1.11225
120	0.00478	2.10919	2.465499	59.1	-1	-1	-1.11225
120	0.00478	2.10919	2.73409	59	-1	-1	-1.11225
120	0.00478	2.10919	3.041734	58.2	-1	-1	-1.11225
140	0.00478	2.10919	2.27604	65.5	-0.33333	-1	-1.11225
140	0.00478	2.10919	2.465499	69.5	-0.33333	-1	-1.11225
140	0.00478	2.10919	2.73409	69.3	-0.33333	-1	-1.11225
160	0.00478	2.10919	4.534037	70.6	0.333333	-1	-1.11225
160	0.00478	2.10919	4.934874	69.2	0.333333	-1	-1.11225
180	0.00478	2.10919	3.77705	84.5	1	-1	-1.11225
180	0.00478	2.10919	3.985914	83.5	1	-1	-1.11225
120	0.00139	2.27604	1.4061	53.7	-1	-1.55483	-1.00235
120	0.00139	2.27604	1.7576	52.7	-1	-1.55483	-1.00235
120	0.00139	2.27604	2.1091	52.2	-1	-1.55483	-1.00235
120	0.00139	2.27604	2.4607	51.3	-1	-1.55483	-1.00235
120	0.00288	2.27604	1.4061	61.6	-1	-1.31097	-1.00235
120	0.00288	2.27604	1.7576	60.6	-1	-1.31097	-1.00235
120	0.00288	2.27604	2.1091	60	-1	-1.31097	-1.00235
120	0.00478	2.27604	4.5699	53.4	-1	-1	-1.00235
120	0.00478	2.27604	4.9214	53.2	-1	-1	-1.00235
120	0.00478	2.27604	5.2729	52.6	-1	-1	-1.00235

Contd.table-56

Ceff	Deff	AB eff	AC eff	AD eff	BC eff	BD eff
-1	-1	1	1	1	1	1
-1	-1	-1	1	-1	1	1
-1	-1	-1	-1	1	-1	-1
-1	-1	1	-1	-1	-1	-1
1	-1	1	-1	1	-1	1
1	-1	-1	-1	-1	-1	1
1	-1	-1	1	1	1	-1
1	-1	1	1	-1	1	-1
-1	1	1	1	-1	1	-1
-1	1	-1	1	1	1	-1
-1	1	-1	-1	-1	-1	1
-1	1	1	-1	1	-1	1
1	1	1	-1	-1	-1	-1
1	1	-1	-1	1	-1	-1
1	1	-1	1	-1	1	1
1	1	1	1	1	1	1
-1.11225	-0.84178	1	1.11225	0.841782	1.11225	0.841782
-1.11225	-0.66212	1	1.11225	0.662124	1.11225	0.662124
-1.11225	-0.40743	1	1.11225	0.407428	1.11225	0.407428
-1.11225	-0.1157	1	1.11225	0.115699	1.11225	0.115699
-1.11225	-0.84178	0.333333	1.11225	0.280594	1.11225	0.841782
-1.11225	-0.66212	0.333333	1.11225	0.220708	1.11225	0.662124
-1.11225	-0.40743	0.333333	1.11225	0.135809	1.11225	0.407428
-1.11225	1.299403	-0.33333	1.11225	0.433134	1.11225	-1.2994
-1.11225	1.679504	-0.33333	1.11225	0.559835	1.11225	-1.6795
-1.11225	0.581577	-1	1.11225	0.581577	1.11225	-0.58158
-1.11225	0.779636	-1	1.11225	0.779636	1.11225	-0.77964
-1.00235	-1.66672	1.554828	1.558478	1.666717	1.558478	2.591459
-1.00235	-1.3334	1.554828	1.558478	1.333401	1.558478	2.07321
-1.00235	-1.00009	1.554828	1.558478	1.000085	1.558478	1.554961
-1.00235	-0.66667	1.554828	1.558478	0.666675	1.558478	1.036564
-1.00235	-1.66672	1.310966	1.314043	1.666717	1.314043	2.185009
-1.00235	-1.3334	1.310966	1.314043	1.333401	1.314043	1.748043
-1.00235	-1.00009	1.310966	1.314043	1.000085	1.314043	1.311078
-1.00235	1.333411	1	1.002348	-1.33341	1.002348	-1.33341
-1.00235	1.666727	1	1.002348	-1.66673	1.002348	-1.66673
-1.00235	2.000043	1	1.002348	-2.00004	1.002348	-2.00004

Contd.table-56

CD eff	ABC eff	ABD eff	ACD eff	BCD eff	ABCD eff	To cal	%Dev
1	-1	-1	-1	-1	1	58.9122	-0.87705
1	1	1	-1	-1	-1	63.3622	2.669432
1	1	1	1	1	-1	71.6603	-0.93
1	-1	-1	1	1	1	74.7093	-0.68639
-1	1	-1	1	1	-1	57.8852	0.881507
-1	-1	1	1	1	1	62.3352	-2.86337
-1	-1	1	-1	-1	1	65.8383	0.995038
-1	1	-1	-1	-1	-1	68.8873	0.738761
-1	-1	1	1	1	-1	57.8872	0.878082
-1	1	-1	1	1	1	51.9122	-5.29858
-1	1	-1	-1	-1	1	43.8603	3.39141
-1	-1	1	-1	-1	-1	39.9843	1.273333
1	1	1	-1	-1	1	58.9102	-0.87363
1	-1	-1	-1	-1	-1	51.7852	4.806618
1	-1	-1	1	1	-1	54.8383	-2.88612
1	1	1	1	1	1	52.1123	-0.99283
0.936272	-1.11225	-0.84178	-0.93627	-0.93627	0.936272	58.87965	-0.47722
0.736447	-1.11225	-0.66212	-0.73645	-0.73645	0.736447	58.77724	0.546123
0.453162	-1.11225	-0.40743	-0.45316	-0.45316	0.453162	58.63206	0.623631
0.128686	-1.11225	-0.1157	-0.12869	-0.12869	0.128686	58.46576	-0.45664
0.936272	-0.37075	-0.28059	-0.93627	-0.93627	0.312091	60.08978	8.259874
0.736447	-0.37075	-0.22071	-0.73645	-0.73645	0.245482	59.67715	14.1336
0.453162	-0.37075	-0.13581	-0.45316	-0.45316	0.151054	59.09217	14.72991
-1.44526	0.37075	-0.43313	1.445261	1.445261	0.481754	52.68483	25.3756
-1.86803	0.37075	-0.55983	1.868028	1.868028	0.622676	51.15549	26.07588
-0.64686	1.11225	-0.58158	0.646859	0.646859	0.646859	54.32537	35.70962
-0.86715	1.11225	-0.77964	0.86715	0.86715	0.86715	53.18648	36.30362
1.67063	-1.55848	-2.59146	-2.59754	-2.59754	2.597543	53.24013	0.856374
1.336532	-1.55848	-2.07321	-2.07808	-2.07808	2.078077	54.3076	-3.05047
1.002433	-1.55848	-1.55496	-1.55861	-1.55861	1.558611	55.37507	-6.08251
0.66824	-1.55848	-1.03656	-1.039	-1.039	1.038998	56.44284	-10.025
1.67063	-1.31404	-2.18501	-2.19014	-2.19014	2.190138	55.88423	9.278851
1.336532	-1.31404	-1.74804	-1.75215	-1.75215	1.752147	56.40726	6.918718
1.002433	-1.31404	-1.31108	-1.31416	-1.31416	1.314155	56.93029	5.11619
-1.33654	-1.00235	1.333411	1.336541	1.336541	-1.33654	57.71473	-8.08001
-1.67064	-1.00235	1.666727	1.670639	1.670639	-1.67064	57.5435	-8.16447
-2.00474	-1.00235	2.000043	2.004738	2.004738	-2.00474	57.37227	-9.07276

Table-57: comparison table for outlet temperature of salt solution

dimensional analysis method			fractionalfactorial design			ANN method		
exp.To	cal. To	%dev.	exp.To	calTo	%dev.	exp.To	cal. To	%dev
^{o}C						^{o}C		
51.2	51.927	-1.421	51.2	51.2	0	51.2	43.51374	15.01223
60.7	58.65	3.3698	69.5	69.504	-0.0058	60.7	46.14804	23.97357
68.2	65.181	4.4254	58.2	58.2	0	68.2	48.8682	28.34575
69.5	71.539	-2.934	61.4	61.416	-0.0261	69.5	51.66612	25.66026
58.2	59.334	-1.949	49.6	49.612	-0.0242	58.2	43.51392	25.23381
61.4	63.598	-3.58	46.4	46.412	-0.0259	61.4	43.51392	29.13042
66.5	67.151	-0.979	47.5	47.508	-0.0168	66.5	43.5141	34.56526
49.6	47.997	3.2308	44.3	44.308	-0.0181	49.6	43.5078	12.28266
46.4	45.689	1.5311	48.1	48.108	-0.0166	46.4	43.50276	6.244052
42.4	42.773	-0.88	45.2	45.212	-0.0265	42.4	43.49412	-2.58047
47.5	49.628	-4.48	56.5	56.492	0.01416	47.5	43.51644	8.386442
44.3	48.33	-9.098	49.4	49.388	0.02429	44.3	43.51896	1.76307
48.4	47.43	2.0024	66.5	66.48	0.03008	48.4	43.52166	10.07921
48.1	49.637	-3.196	42.4	42.4	0	48.1	43.50834	9.546071
45.2	47.93	-6.041	48.4	48.4	0	45.2	43.50294	3.754558
46.7	46.58	0.2567	46.7	46.72	-0.0428	46.7	43.49736	6.857901
56.5	52.402	7.2515	60.7	53.83	11.318	56.5	42.90858	24.05561
49.4	46.869	5.1234	68.2	58.2	14.6628	49.4	48.15828	2.513603
57.2	54.07	5.4709	49.4	51.2	-3.6437	57.2	40.51386	29.17157

Table-58: comparison table for %Yield of salt solution

dimensional analysis method			fractional factorial design			ANN method		
exp. %Yield	Cal %Yield	%dev.	exp. %Yield	Cal %Yield	%dev.	exp. %Yield	Cal %Yield	%dev
68.6	67.268	0.0194	68.6	68.594	0.008746	68.6	63.37	7.620904
65.8	65.697	0.0015	63.5	63.5015	-0.00236	65.8	64.82034	1.488845
64.5	64.366	0.002	70.4	70.416	-0.02273	64.5	66.2778	-2.75628
63.5	63.214	0.0044	61.9	61.9035	-0.00565	63.5	67.74318	-6.68217
70.4	63.343	0.1002	60.54	60.549	-0.01487	70.4	63.37224	9.982614
61.9	61.391	0.0082	56.27	56.2565	0.023991	61.9	63.37224	-2.37842
59.9	59.905	-8.80E-5	69.9	69.911	-0.01574	59.9	63.37242	-5.79703
60.54	53.524	0.1158	71.26	71.2385	0.030171	60.54	63.37548	-4.683565
56.27	46.388	0.1756	55.4	55.4015	-0.00271	56.27	63.37836	-12.6326
32.9	38.303	-0.164	60.2	60.189	0.018272	32.9	63.38322	-92.6542
69.9	70.416	-0.007	70.29	70.2835	0.009247	69.9	63.3744	9.335622
71.26	72.325	-0.014	64.85	64.851	-0.00154	71.26	63.37674	11.06267
78.14	73.711	0.0566	59.9	59.8965	0.005843	78.14	63.37908	18.89035
55.4	62.567	-0.129	32.9	32.924	-0.07295	55.4	63.39654	-14.4342
60.2	59.148	0.0174	78.14	78.1185	0.027515	60.2	63.42084	-5.35023
52.83	56.495	-0.069	52.83	52.846	-0.03029	52.83	63.44514	-20.093
70.29	67.085	0.0455	65.8	65.61246	0.285015	70.29	63.27972	9.973367
64.85	69.358	-0.069	64.5	63.04162	2.261054	64.85	64.04634	1.23926
57.18	66.461	-0.162	57.18	67.90401	-18.7548	57.18	62.90298	-10.0087

Table-59: comparison table for outlet temperature of blank solution(water).

dimensional analysis method			fractional factorial design			ANN method		
exp. To °C	cal.. To °C	%dev.	exp. To °C	cal.. To °C	%dev.	exp. To °C	cal.. To °C	%dev.
58.4	58.0618	0.5791	58.4	58.9122	-0.87705	58.4	54.03564	7.473219
65.1	63.77664	2.0328	65.1	63.3622	2.669432	65.1	54.3384	16.53088
71	69.17979	2.5636	71	71.6603	-0.93	71	54.6417	23.03986
74.2	74.32443	-0.1676	74.2	74.7093	-0.68639	74.2	54.94554	25.94941
58.4	58.0618	0.5791	58.4	57.8852	0.881507	58.4	54.03582	7.472911
60.6	63.68311	-5.0876	60.6	62.3352	-2.86337	60.6	54.03582	10.83198
66.5	66.82107	-0.4828	66.5	65.8383	0.995038	66.5	54.03582	18.74313
69.4	69.38656	0.0193	69.4	68.8873	0.738761	69.4	54.02988	22.14715
58.4	58.0618	0.5791	58.4	57.8872	0.878082	58.4	54.0252	7.491096
49.3	49.97605	-1.3712	49.3	51.9122	-5.29858	49.3	54.01692	-9.56779
45.4	45.4971	-0.2138	45.4	43.8603	3.39141	45.4	54.03564	-19.0212
40.5	40.12436	0.9275	40.5	39.9843	1.273333	40.5	54.03564	-33.4213
58.4	58.0618	0.5791	58.4	58.9102	-0.87363	58.4	54.03564	7.473219
54.4	55.21422	-1.4967	54.4	51.7852	4.806618	54.4	54.03564	0.669779
53.3	53.10168	0.372	53.3	54.8383	-2.88612	53.3	54.03564	-1.38019
51.6	51.43607	0.3176	51.6	52.1123	-0.99283	51.6	54.03564	-4.72023

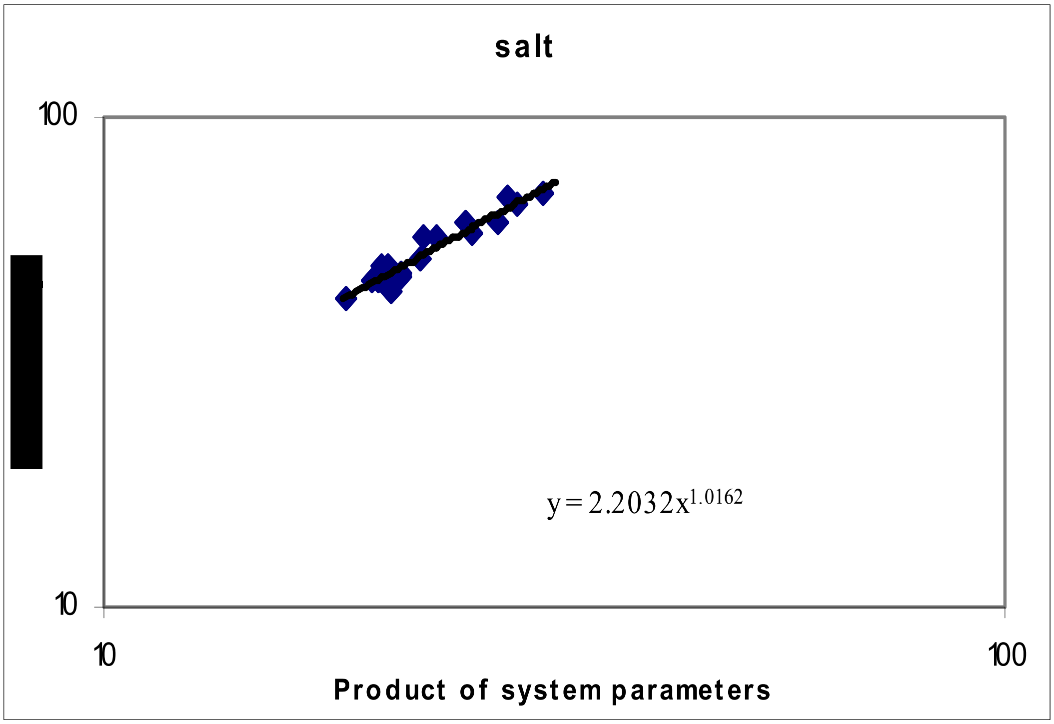

Figure-42

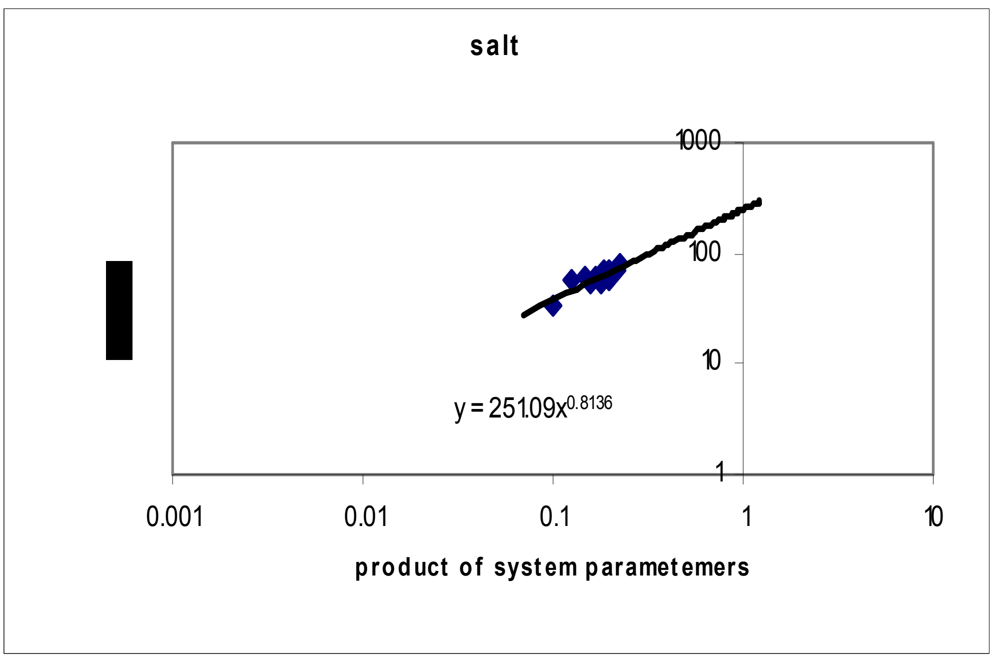

Figure-43

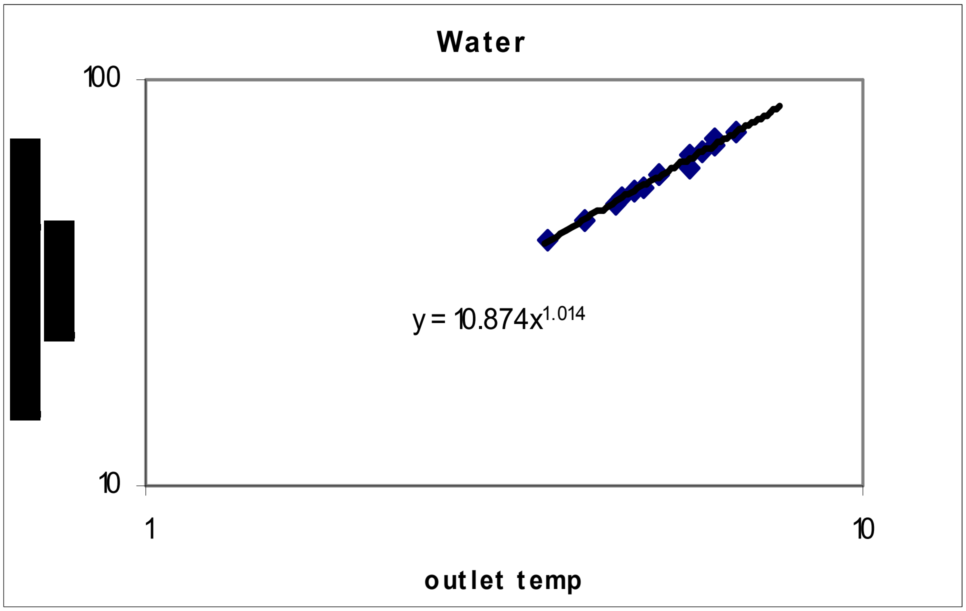

Figure-44

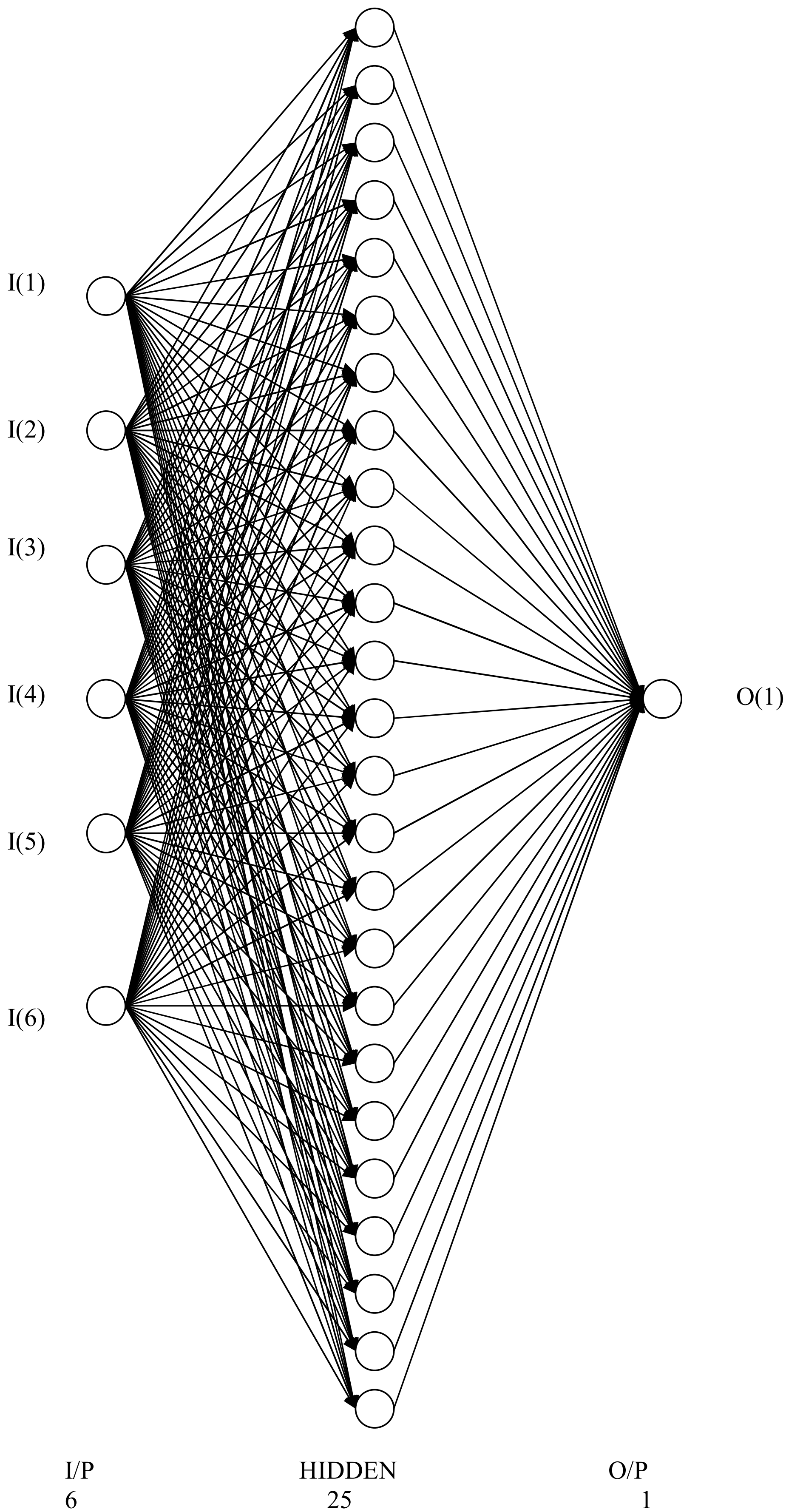

Figure-77:Optimum structure for Artificial Neural Network : salt solution (outlet temperature)

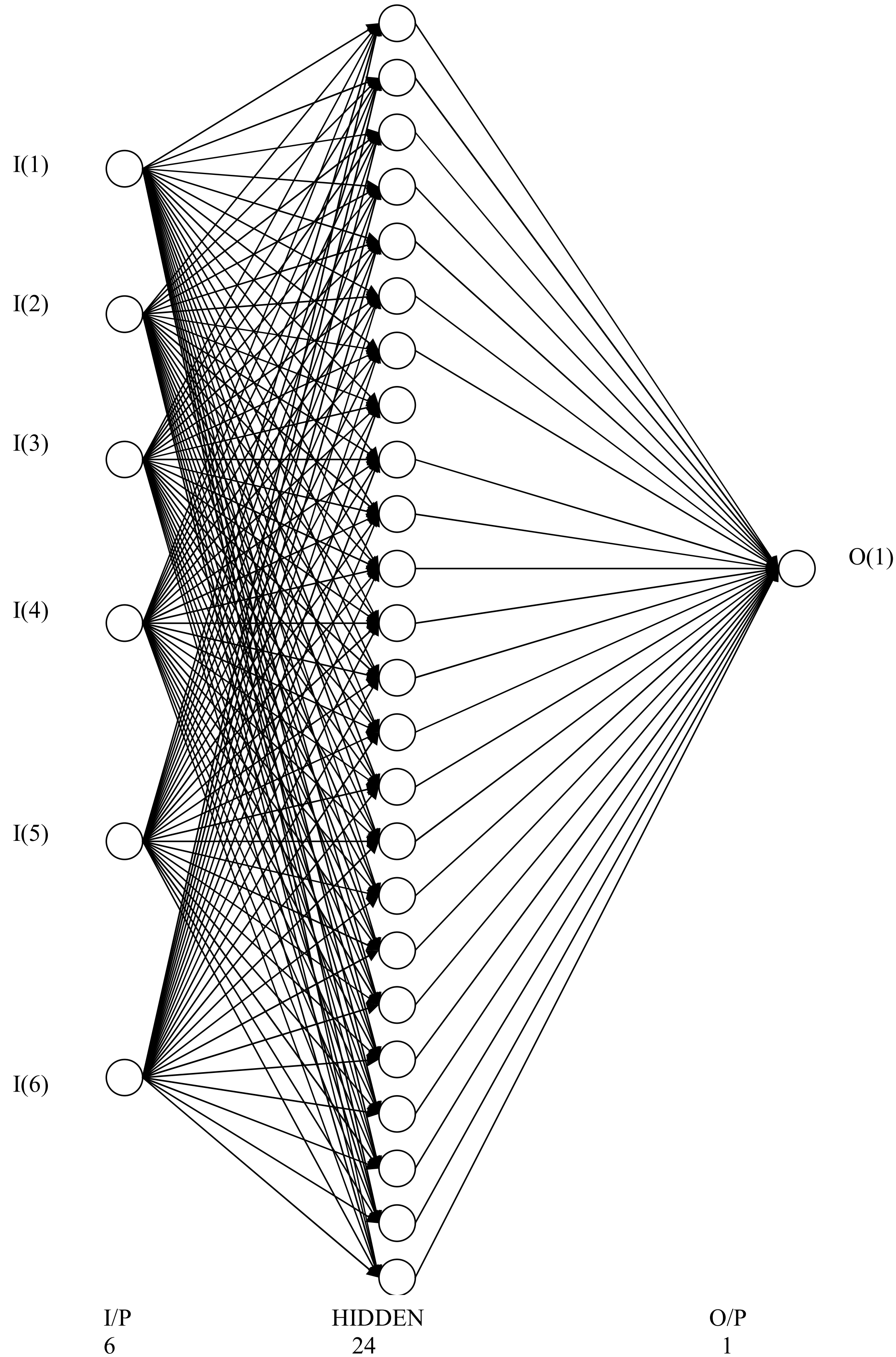

Figure-78:Optimum structure for Artificial Neural Network : salt solution (% Yield)

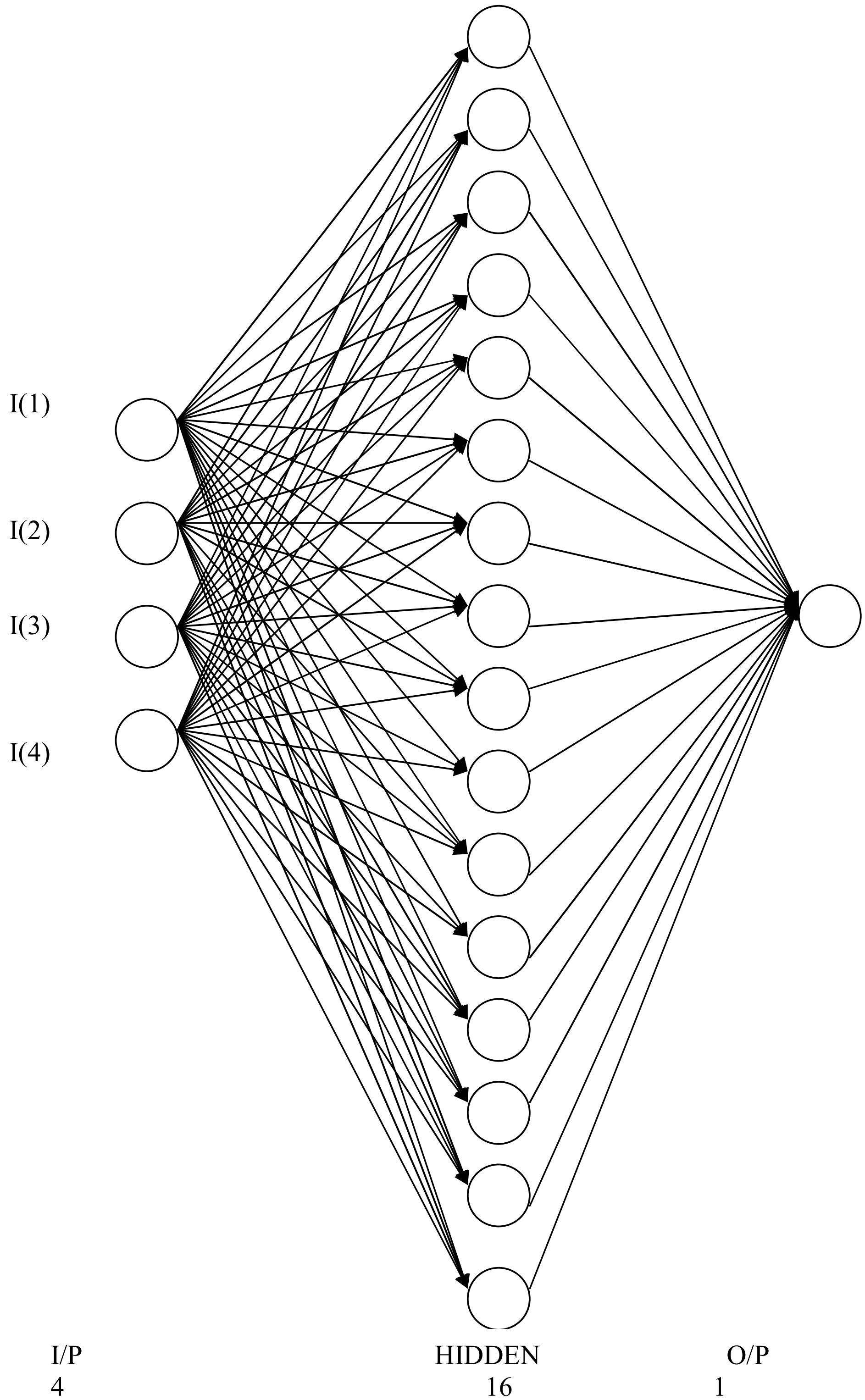

Figure-79:Optimum structure for Artificial Neural Network : blank solution;water (outlet temperature)

CHAPTER-V

Conclusion

Spray dried powders are mostly used in food and pharmaceutical industries. For pharmaceutical purpose the powders should have appropriate aerodynamic properties and minimum moisture content which can be produced through spray dryer by maintaining the optimum parametric conditions. The present studies reveal how the particle morphologies are being affected with the variation of parametric conditions of the dryer and the physical characteristics of the sample solutions. Agglomeration during spray drying depends on drying air temperature in the atomization zone, pump flow rate and atomization rate. Proper care should be taken in food industries for the preparation of infant food, instant food mix etc. for the moisture free and unaltered product. It is essential to have a good understanding of the effects of the process inputs on the final characteristics of the dried product particles for many reasons. Good process knowledge would lead to better productivity, low operational costs, and improved quality of the final product. For example, in the case of ceramic industries, it is important that the powder has a certain mean particle diameter and minimum moisture content in order to ensure a flow able product with uniform bulk density. It is well-known that these critical product characteristics are functions of slurry properties (such as surface tension, viscosity, density, additives, and solids content), atomization technique, bulk flow and temperature of the drying air (droplet air mixing), and liquid slurry feed rate

These studies with the developed models can have wide applications in food, ceramics, chemical and pharmaceutical industries over a wide range of system parameters.

This work can further be extended

(i) by varying two or more parameters at a time and observing the changes in the characteristics of the dried product.

(ii) and by making further provision for observing the spray particle size and characteristics in the dry chamber.

Nomenclature

a,b,c,d,e,f ,n	: Exponents
To	: Outlet temperature, ^oC
Y	: % Yield
Ti	: Inlet temperature, ^oC
Uasp	: Aspirator Speed, kg/cm^2
Up	: Pump flow rate, ml/ min
Piair	: Atomization rate, kg/cm^2
Cs	: Concentration of salt, gm/ml
Ms	: Moleccular weight of salt
K	: Coefficient of the correlation
$(NH_4)_2SO_4$	: Ammonium Sulfate
NaCl	: Sodium Chloride
Na_2SO_4	: Sodium Sulfate
$C_6H_{14}O_6$	: Mannitol

Suffixes:

1 : outlet temperature

2 : % Yield

‘ : water

ANN : Artificial Neural Network

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APPENDIX-1

Observed Data Tables

Table 18, Variation of outlet temperature with respect to inlet temperature

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/ cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	$(NH_4)_2SO_4$	132.13	140	0.00478	2.279604	0.1	2.10919	60.7
3	$(NH_4)_2SO_4$	132.13	160	0.00478	2.279604	0.1	2.10919	68.2
4	$(NH_4)_2SO_4$	132.13	180	0.00478	2.279604	0.1	2.10919	69.5

Table 19, Variation of outlet temperature with respect to aspirator speed.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/ cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	$(NH_4)_2SO_4$	132.13	120	0.00923	2.279604	0.1	2.10919	58.2
3	$(NH_4)_2SO_4$	132.13	120	0.013	2.279604	0.1	2.10919	61.4
4	$(NH_4)_2SO_4$	132.13	120	0.017	2.279604	0.1	2.10919	66.5

Table 20, Variation of outlet temperature with respect to pump flow rate.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/ cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	$(NH_4)_2SO_4$	132.13	120	0.00478	3.214336	0.1	2.10919	49.6
3	$(NH_4)_2SO_4$	132.13	120	0.00478	3.985914	0.1	2.10919	46.4
4	$(NH_4)_2SO_4$	132.13	120	0.00478	5.315932	0.1	2.10919	42.4

Table 21, Variation of outlet temperature with respect to concentration of salt solution.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/ cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.2	2.10919	47.5
3	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.3	2.10919	44.3
4	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.4	2.10919	48.4

Table 22, Variation of outlet temperature with respect to atomization rate.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/ cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.8122	48.1
3	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	3.51532	45.2
4	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	4.2183	46.7

Table 23, Variation of outlet temperature with respect to molecular weight of salt.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	To, °C
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	51.2
2	Na_2SO_4	142.04	120	0.00478	2.279604	0.1	2.10919	56.5
3	NaCl	58.54	120	0.00478	2.279604	0.1	2.10919	49.1
4	$C_6H_{14}O_6$	182.17	120	0.00478	2.279604	0.1	2.10919	57.2

Table 24, Variation of yield with respect to inlet temperature.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.6
2	$(NH_4)_2SO_4$	132.13	140	0.00478	2.279604	0.1	2.10919	65.8
3	$(NH_4)_2SO_4$	132.13	160	0.00478	2.279604	0.1	2.10919	64.5
4	$(NH_4)_2SO_4$	132.13	180	0.00478	2.279604	0.1	2.10919	63.5

Table 25, Variation of yield with respect to aspirator speed.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.5
2	$(NH_4)_2SO_4$	132.13	120	0.00923	2.279604	0.1	2.10919	70.4
3	$(NH_4)_2SO_4$	132.13	120	0.013	2.279604	0.1	2.10919	61.9
4	$(NH_4)_2SO_4$	132.13	120	0.017	2.279604	0.1	2.10919	59.9

Table 26, Variation of yield with respect to pump flow rate.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.5
2	$(NH_4)_2SO_4$	132.13	120	0.00478	3.214336	0.1	2.10919	60.54
3	$(NH_4)_2SO_4$	132.13	120	0.00478	3.985914	0.1	2.10919	56.27
4	$(NH_4)_2SO_4$	132.13	120	0.00478	5.315932	0.1	2.10919	32.9

Table 27, Variation of yield with respect to concentration of salt solution.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.5
2	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.2	2.10919	69.9
3	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.3	2.10919	71.26
4	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.4	2.10919	78.14

Table 28, Variation of yield with respect to atomization rate.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.5
2	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.8122	55.4
3	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	3.51532	60.2
4	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	4.2183	52.83

Table 29, Variation of yield with respect to molecular weight of salt.

Sr no	Salt	Ms	Ti, °C	Uasp,Kg/cm^2	Up, ml/min	Cs, gm/ml	Piair,kg/cm^2	Y
1	$(NH_4)_2SO_4$	132.13	120	0.00478	2.279604	0.1	2.10919	68.5
2	Na_2SO_4	142.04	120	0.00478	2.279604	0.1	2.10919	70.29
3	NaCl	58.54	120	0.00478	2.279604	0.1	2.10919	64.85
4	$C_6H_{14}O_6$	182.17	120	0.00478	2.279604	0.1	2.10919	57.18

Data analysis for water:

Table 30, Variation of outlet temperature with respect to inlet temperature.

Sr No	Ti, °C	Uasp Kg/cm^2	Up, ml/min	Piair, kg/cm^2	To, °C
1	120	0.00478	2.279604	2.10919	58.4
2	140	0.00478	2.279604	2.10919	65.1
3	160	0.00478	2.279604	2.10919	71
4	180	0.00478	2.279604	2.10919	74.2

Table 31, Variation of outlet temperature with respect to aspirator speed.

Sr No	Ti, °C	Uasp Kg/cm^2	Up, ml/min	Piair, kg/cm^2	To, °C
1	120	0.00478	2.279604	2.10919	58.4
2	120	0.00923	2.279604	2.10919	60.6
3	120	0.013	2.279604	2.10919	66.5
4	120	0.017	2.279604	2.10919	69.4

Table 32, Variation of outlet temperature with respect to pump flow rate.

Sr No	Ti, °C	Uasp Kg/cm^2	Up, ml/min	Piair, kg/cm^2	To, °C
1	120	0.00478	2.279604	2.10919	58.4
2	120	0.00478	3.214336	2.10919	49.3
3	120	0.00478	3.985914	2.10919	45.4
4	120	0.00478	5.315932	2.10919	40.5

Table 33, Variation of outlet temperature with respect to atomization rate.

Sr No	Ti, °C	Uasp Kg/cm^2	Up, ml/min	Piair,kg/cm^2	To, °C
1	120	0.00478	2.279604	2.10919	58.4
2	120	0.00478	2.279604	2.8122	54.4
3	120	0.00478	2.279604	3.51532	53.3
4	120	0.00478	2.279604	4.2183	51.6

Table 34 : Outlet temperature vs Pump flow rate varying Inlet temperature.

Sr No	Ti, ^oC	Piair, kg/cm^2	Uasp,Kg/cm^2	Up, ml/min	To, ^oC
1	120	2.10919	0.00478	2.27604	58.6
2	120	2.10919	0.00478	2.465499	59.1
3	120	2.10919	0.00478	2.73409	59
4	120	2.10919	0.00478	3.041734	58.2
5	120	2.10919	0.00478	3.214336	57
6	120	2.10919	0.00478	3.520529	56.1

Table 35

Sr No	Ti, ^oC	Piair, kg/cm^2	Uasp,Kg/cm^2	Up, ml/min	To, ^oC
1	140	2.10919	0.00478	2.27604	65.5
2	140	2.10919	0.00478	2.465499	69.5
3	140	2.10919	0.00478	2.73409	69.3
4	140	2.10919	0.00478	3.041734	68.7
5	140	2.10919	0.00478	3.214336	68.2
6	140	2.10919	0.00478	3.520529	67.1
7	140	2.10919	0.00478	3.77705	66.4
8	140	2.10919	0.00478	3.985914	65.6
9	140	2.10919	0.00478	4.322841	64.3
10	140	2.10919	0.00478	4.534037	64
11	140	2.10919	0.00478	4.934874	63
12	140	2.10919	0.00478	5.11576	62.1

Table 36

Sr No	Ti, ^oC	Piair, kg/cm^2	Uasp,Kg/cm^2	Up, ml/min	To, ^oC
1	160	2.10919	0.00478	2.27604	76.9
2	160	2.10919	0.00478	2.465499	76.8
3	160	2.10919	0.00478	2.73409	76.2
4	160	2.10919	0.00478	3.041734	75.9
5	160	2.10919	0.00478	3.214336	74.5
6	160	2.10919	0.00478	3.520529	74.3
7	160	2.10919	0.00478	3.77705	73
8	160	2.10919	0.00478	3.985914	72.2
9	160	2.10919	0.00478	4.322841	71.2
10	160	2.10919	0.00478	4.534037	70.6
11	160	2.10919	0.00478	4.934874	69.2
12	160	2.10919	0.00478	5.11576	67.7

Table-37

Sr No	Ti, ^oC	Piair, kg/cm^2	Uasp, Kg/ cm^2	Up, ml/min	To, ^oC
1	180	2.10919	0.00478	2.27604	87.7
2	180	2.10919	0.00478	2.465499	88.1
3	180	2.10919	0.00478	2.73409	87.8
4	180	2.10919	0.00478	3.041734	87.5
5	180	2.10919	0.00478	3.214336	86.6
6	180	2.10919	0.00478	3.520529	85.9
7	180	2.10919	0.00478	3.77705	84.5
8	180	2.10919	0.00478	3.985914	83.5
9	180	2.10919	0.00478	4.322841	82.5
10	180	2.10919	0.00478	4.534037	81.2
11	180	2.10919	0.00478	4.934874	79.1
12	180	2.10919	0.00478	5.11576	78.8

Table-38: Outlet temperature vs Atomization rate varying Aspirator speed.

Sr No	Ti, ^oC	Up, ml/min	Uasp, Kg/ cm^2	Piair, kg/cm^2	To, ^oC
1	120	2.27604	0.00139	0	70
2	120	2.27604	0.00139	0.3515	57.7
3	120	2.27604	0.00139	0.7070	57.3
4	120	2.27604	0.00139	1.0545	55
5	120	2.27604	0.00139	1.4061	53.7
6	120	2.27604	0.00139	1.7576	52.7
7	120	2.27604	0.00139	2.1091	52.2
8	120	2.27604	0.00139	2.4607	51.3
9	120	2.27604	0.00139	2.8122	50.2
10	120	2.27604	0.00139	3.1637	49.7
11	120	2.27604	0.00139	3.5153	47.4
12	120	2.27604	0.00139	3.8668	46.6
13	120	2.27604	0.00139	4.2183	45.6

Table-39

Sr No	Ti, °C	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, °C
1	120	2.27604	0.00288	0	72
2	120	2.27604	0.00288	0.3515	66.5
3	120	2.27604	0.00288	0.7070	64.5
4	120	2.27604	0.00288	1.0545	62.6
5	120	2.27604	0.00288	1.4061	61.6
6	120	2.27604	0.00288	1.7576	60.6
7	120	2.27604	0.00288	2.1091	60
8	120	2.27604	0.00288	2.4607	58.6
9	120	2.27604	0.00288	2.8122	57.3
10	120	2.27604	0.00288	3.1637	56.3
11	120	2.27604	0.00288	3.5153	55.7
12	120	2.27604	0.00288	3.8668	54.7
13	120	2.27604	0.00288	4.2183	53.5
14	120	2.27604	0.00288	4.5699	52.1

Table-40

Sr No	Ti, °C	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, °C
1	120	2.27604	0.00478	0	73
2	120	2.27604	0.00478	0.3515	62.1
3	120	2.27604	0.00478	0.7070	60.1
4	120	2.27604	0.00478	1.0545	58.9
5	120	2.27604	0.00478	1.4061	58
6	120	2.27604	0.00478	1.7576	57.7
7	120	2.27604	0.00478	2.1091	57.4
8	120	2.27604	0.00478	2.4607	57
9	120	2.27604	0.00478	2.8122	56.2
10	120	2.27604	0.00478	3.1637	55.8
11	120	2.27604	0.00478	3.5153	55
12	120	2.27604	0.00478	3.8668	54.6
13	120	2.27604	0.00478	4.2183	53.9
14	120	2.27604	0.00478	4.5699	53.4
15	120	2.27604	0.00478	4.9214	53.2
16	120	2.27604	0.00478	5.2729	52.6

Table-41

Sr No	Ti, ^oC	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, ^oC
1	120	2.27604	0.00699	0	74.5
2	120	2.27604	0.00699	0.3515	63.6
3	120	2.27604	0.00699	0.7070	62.7
4	120	2.27604	0.00699	1.0545	61.8
5	120	2.27604	0.00699	1.4061	61.5
6	120	2.27604	0.00699	1.7576	61.3
7	120	2.27604	0.00699	2.1091	61
8	120	2.27604	0.00699	2.4607	60.7
9	120	2.27604	0.00699	2.8122	60.2
10	120	2.27604	0.00699	3.1637	59.8
11	120	2.27604	0.00699	3.5153	59.5
12	120	2.27604	0.00699	3.8668	57.6
13	120	2.27604	0.00699	4.2183	57.2
14	120	2.27604	0.00699	4.5699	56.7
15	120	2.27604	0.00699	4.9214	55.7

Table-42

Sr No	Ti, ^oC	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, ^oC
1	120	2.27604	0.00923	0	75.4
2	120	2.27604	0.00923	0.3515	68.2
3	120	2.27604	0.00923	0.7070	67.1
4	120	2.27604	0.00923	1.0545	66.2
5	120	2.27604	0.00923	1.4061	65.3
6	120	2.27604	0.00923	1.7576	64.3
7	120	2.27604	0.00923	2.1091	64.1
8	120	2.27604	0.00923	2.4607	63.7
9	120	2.27604	0.00923	2.8122	63.1
10	120	2.27604	0.00923	3.1637	62.8
11	120	2.27604	0.00923	3.5153	62.3
12	120	2.27604	0.00923	3.8668	62
13	120	2.27604	0.00923	4.2183	61.7
14	120	2.27604	0.00923	4.5699	60.9
15	120	2.27604	0.00923	4.9214	60.4

Table-43

Sr No	Ti, ^oC	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, ^oC
1	120	2.27604	0.0113	0	87.4
2	120	2.27604	0.0113	0.3515	74
3	120	2.27604	0.0113	0.7070	71.6
4	120	2.27604	0.0113	1.0545	70.8
5	120	2.27604	0.0113	1.4061	70.2
6	120	2.27604	0.0113	1.7576	69.7
7	120	2.27604	0.0113	2.1091	69.2
8	120	2.27604	0.0113	2.4607	68.5
9	120	2.27604	0.0113	2.8122	67.7
10	120	2.27604	0.0113	3.1637	66.6
11	120	2.27604	0.0113	3.5153	66
12	120	2.27604	0.0113	3.8668	64.6
13	120	2.27604	0.0113	4.2183	63.6
14	120	2.27604	0.0113	4.5699	63.4
15	120	2.27604	0.0113	4.9214	63

Table-44

Sr No	Ti, ^oC	Up, ml/min	Uasp, Kg/cm^2	Piair, kg/cm^2	To, ^oC
1	120	2.27604	0.013	0	88.7
2	120	2.27604	0.013	0.3515	71.2
3	120	2.27604	0.013	0.7070	70.7
4	120	2.27604	0.013	1.0545	70.4
5	120	2.27604	0.013	1.4061	69.9
6	120	2.27604	0.013	1.7576	69.4
7	120	2.27604	0.013	2.1091	68.4
8	120	2.27604	0.013	2.4607	67.8
9	120	2.27604	0.013	2.8122	67
10	120	2.27604	0.013	3.1637	66.3
11	120	2.27604	0.013	3.5153	65.4
12	120	2.27604	0.013	3.8668	64.8
13	120	2.27604	0.013	4.2183	64
14	120	2.27604	0.013	4.5699	63.7
15	120	2.27604	0.013	4.9214	63.2

Table-60

Weights obtained from the training of the ANN learning for both salt solution and blank solution(water):

Weight of training dataset-1

```
0.200000

3
4 16 1


1 0.733303 0.791096 -0.730371 -0.345164 -0.788160 0.020727 0.636988 -
0.788167 0.598473 0.752575 0.020726 0.848899 -0.865218 -0.576278
0.213297 -0.884494
1 -0.500000 0.799999 -0.859999 0.940000 -0.839999 -0.760000 -0.320001 -
0.959999 0.219999 0.279999 -0.160000 -0.840001 -0.039998 0.880000 -
0.600000 0.360001
1 -0.960594 -0.420644 0.180664 -0.359666 0.180714 -0.499981 -0.820512
0.980714 -0.620479 0.419389 -0.459982 0.659307 0.800780 0.360532 -
0.240148 0.300796
1 0.099487 -0.020556 0.540573 -0.439713 0.960615 0.080015 -0.900442 -
0.959385 0.459587 0.139473 -0.439985 0.039402 0.540672 -0.499541
0.279872 -0.119314
2 0.197777
2 0.255189
2 -1.267058
2 -0.880749
2 -1.325137
2 -0.515120
2 0.102084
2 -1.324426
2 0.062425
2 0.215860
2 -0.514781
2 0.312031
2 -1.402390
2 -1.112397
2 -0.322911
2 -1.420763
```

Table-61

Weight of training data set-2

```
0.600000

3
6 25 1


1 -0.080000 -0.980000 0.840000 0.720000 0.060000 -0.880000 -0.680000
0.200000 0.000000 -0.180000 0.060000 -0.460000 -0.880000 -0.200000
0.300000 -0.880000 0.020000 -0.820000 -0.160000 -0.600000 -0.860000
0.680000 -0.060000 0.500000 -0.240000
1 -0.600000 0.200000 0.760000 -0.600000 0.640000 -0.500000 -0.920000 -
0.240000 0.500000 -0.280000 0.000000 -0.440000 0.760000 0.900000 -
0.960000 -0.240000 0.680000 -0.700000 0.060000 -0.360000 -0.360000 -
0.460000 -0.020000 0.440000 0.620000
1 -0.580000 -0.220000 0.120000 0.960000 0.500000 0.320000 0.960000 -
1.000000 -0.460000 -0.300000 -0.880000 0.100000 0.260000 0.660000 -
0.800000 -0.080000 0.740000 -0.840000 -0.500000 0.060000 0.140000
0.360000 0.660000 -0.880000 0.820000
1 0.160000 -0.640000 0.640000 0.720000 -0.080000 0.280000 0.300000
0.800000 -0.700000 -1.000000 0.200000 0.840000 0.160000 -0.780000
0.720000 0.520000 0.960000 -0.180000 -0.020000 -0.760000 -0.180000
0.620000 -0.080000 -0.980000 0.540000
1 -0.820000 0.960000 0.840000 -0.200000 0.160000 0.400000 0.580000 -
0.040000 0.440000 0.880000 -0.520000 -0.060000 -1.000000 -0.880000 -
0.400000 0.160000 0.260000 0.100000 0.100000 -0.840000 0.800000 -
0.220000 0.560000 0.940000 -0.100000
1 0.360000 0.480000 -0.700000 -0.200000 0.800000 0.620000 0.200000 -
0.280000 0.820000 0.700000 0.620000 0.500000 -0.400000 0.120000 -
0.480000 0.180000 -0.920000 0.180000 0.580000 0.760000 0.920000 -
0.240000 0.420000 0.900000 0.920000
2 -0.080000
2 -0.980000
2 0.840000
2 0.720000
2 0.060000
2 -0.880000
2 -0.680000
2 0.200000
2 0.000000
2 -0.180000
2 0.060000
2 -0.460000
2 -0.880000
2 -0.200000
2 0.300000
2 -0.880000
2 0.020000
2 -0.820000
2 -0.160000
2 -0.600000
2 -0.860000
2 0.680000
2 -0.060000
2 0.500000
2 -0.240000
```

Table-62

Weight of training data set-3

```
0.400000

3
6 24 1


1 -0.291101 -0.857851 -0.388692 0.958353 0.099062 0.489231 0.508866 -
0.524868 -0.622373 -0.310831 -0.856777 0.138504 0.645256 -0.135099
0.841178 0.255671 0.470372 0.040566 -0.914916 0.079634 0.918452
0.431212 -0.856998 -0.154660
1 -0.999999 -0.719999 0.240001 -0.360001 -0.040000 0.280000 -0.600001
0.780001 0.040001 -0.579999 -0.999999 0.960000 -0.440001 -0.640000
0.019999 0.720000 0.400000 -1.000000 -0.079999 0.740000 0.739999 -
0.480000 -0.239999 0.840000
1 0.020203 0.680492 -0.679745 -0.640460 -0.840011 0.039776 0.979769
0.140340 -0.219606 -0.619791 -0.459484 0.799979 -0.060310 0.580116 -
0.300398 -0.240082 -0.000197 -0.459978 -0.199444 0.140002 -0.080458
0.039821 -0.099489 -0.359875
1 -0.639996 -0.719989 0.400005 0.659988 0.779999 -0.720006 -0.600006 -
0.619993 0.620008 0.720004 -0.099989 -0.700001 0.339992 0.460002
0.679990 -0.500003 0.159994 -0.660000 -0.859988 -0.640001 -0.900011
0.399995 -0.839989 -0.659998
1 0.640149 -0.599631 -0.899811 0.059645 -0.660013 0.099825 0.739819 -
0.399747 -0.739706 -0.079846 -0.739614 0.239978 -0.020241 0.300083 -
0.900308 0.019932 0.779844 -0.759988 0.020417 -1.000003 0.259647
0.039858 -0.979617 -0.379909
1 -0.431303 -0.578384 -0.368958 0.198951 -0.800877 -0.770440 -0.310796
0.474765 0.617193 -0.751041 0.282649 0.778588 -0.934307 -0.755196
0.281708 0.895831 0.670669 -0.639414 0.924451 -0.460319 -0.700935
0.531488 0.062438 -0.814770
2 -0.447664
2 -1.009976
2 -0.545707
2 0.786081
2 -0.047713
2 0.340859
2 0.348462
2 -0.703192
2 -0.803826
2 -0.458956
2 -1.029646
2 -0.047997
2 0.500925
2 -0.284040
2 0.667242
2 0.066942
2 0.286471
2 -0.110247
2 -1.104086
2 -0.075780
2 0.768206
2 0.251005
2 -1.024468
2 -0.301349
```

Average output from the program:

1.a. Average output of the testing data set -1 = 0.316637
   b. Normalization factor = 180
   c. Final output = 56.99461 °C

2.a. Average output of the testing data set -2 = 0.246751
   b. Normalization factor = 180
   c. Final output = 44.41522°C

3.a. Average output of the testing data set -3 = 0.354704
   b. Normalization factor = 180
   c. Final output = 63.8468 % Yield

Table-63: A sample of training data set-1

sl.no	Ti	Uasp	Up	Pi-air	To
1	120	0.00478	2.279604	2.10919	58.0618
2	140	0.00478	2.279604	2.10919	63.77664
3	160	0.00478	2.279604	2.10919	69.17979
4	180	0.00478	2.279604	2.10919	74.32443
5	120	0.00478	2.279604	2.10919	58.0618
6	120	0.00923	2.279604	2.10919	63.68311
7	120	0.013	2.279604	2.10919	66.82107
8	120	0.017	2.279604	2.10919	69.38656
9	120	0.00478	2.279604	2.10919	58.0618
10	120	0.00478	3.214336	2.10919	49.97605
11	120	0.00478	3.985914	2.10919	45.4971
12	120	0.00478	5.315932	2.10919	40.12436
13	120	0.00478	2.279604	2.10919	58.0618
14	120	0.00478	2.279604	2.8122	55.21422
15	120	0.00478	2.279604	3.51532	53.10168
16	120	0.00478	2.279604	4.2183	51.43607

Table-64: A sample of testing data set-1

sl no	Ti	Uasp	Up	Pi-air	calTo
1	120	0.00478	2.27604	2.10919	58.10146
2	120	0.00478	2.465499	2.10919	56.10896
3	120	0.00478	2.73409	2.10919	53.63314
4	120	0.00478	3.041734	2.10919	51.19447
5	120	0.00478	3.214336	2.10919	49.97605
6	120	0.00478	3.520529	2.10919	48.03036
7	140	0.00478	2.27604	2.10919	63.82021
8	140	0.00478	2.465499	2.10919	61.63159
9	140	0.00478	2.73409	2.10919	58.91208
10	140	0.00478	3.041734	2.10919	56.23338
11	140	0.00478	3.214336	2.10919	54.89503
12	140	0.00478	3.520529	2.10919	52.75784
13	140	0.00478	3.77705	2.10919	51.16305
14	140	0.00478	3.985914	2.10919	49.97524
15	140	0.00478	4.322841	2.10919	48.23638
16	140	0.00478	4.534037	2.10919	47.2426
17	140	0.00478	4.934874	2.10919	45.52786
18	140	0.00478	5.11576	2.10919	44.81817
19	160	0.00478	2.27604	2.10919	69.22705
20	160	0.00478	2.465499	2.10919	66.85301
21	160	0.00478	2.73409	2.10919	63.90311
22	160	0.00478	3.041734	2.10919	60.99746
23	160	0.00478	3.214336	2.10919	59.54573
24	160	0.00478	3.520529	2.10919	57.22747
25	160	0.00478	3.77705	2.10919	55.49758
26	160	0.00478	3.985914	2.10919	54.20914
27	160	0.00478	4.322841	2.10919	52.32296
28	160	0.00478	4.534037	2.10919	51.24498

Contd table-64

sl no	Ti	Uasp	Up	Pi-air	calTo
29	160	0.00478	4.934874	2.10919	49.38497
30	160	0.00478	5.11576	2.10919	48.61516
31	180	0.00478	2.27604	2.10919	74.3752
32	180	0.00478	2.465499	2.10919	71.82461
33	180	0.00478	2.73409	2.10919	68.65533
34	180	0.00478	3.041734	2.10919	65.53361
35	180	0.00478	3.214336	2.10919	63.97392
36	180	0.00478	3.520529	2.10919	61.48326
37	180	0.00478	3.77705	2.10919	59.62472
38	180	0.00478	3.985914	2.10919	58.24046
39	180	0.00478	4.322841	2.10919	56.21401
40	180	0.00478	4.534037	2.10919	55.05588
41	180	0.00478	4.934874	2.10919	53.05754
42	180	0.00478	5.11576	2.10919	52.23048
43	120	0.00139	2.27604	0.3515	66.81777
44	120	0.00139	2.27604	0.707	59.13398
45	120	0.00139	2.27604	1.0545	55.14228

Contd table-64

sl no	Ti	Uasp	Up	Pi-air	calTo
46	120	0.00139	2.27604	1.4061	52.43706
47	120	0.00139	2.27604	1.7576	50.43107
48	120	0.00139	2.27604	2.1091	48.84915
49	120	0.00139	2.27604	2.4607	47.55008
50	120	0.00139	2.27604	2.8122	46.45305
51	120	0.00139	2.27604	3.1637	45.50642
52	120	0.00139	2.27604	3.5153	44.67576
53	120	0.00139	2.27604	3.8668	43.93762
54	120	0.00139	2.27604	4.2183	43.2744
55	120	0.00288	2.27604	0.3515	74.01569
56	120	0.00288	2.27604	0.707	65.50416
57	120	0.00288	2.27604	1.0545	61.08246
58	120	0.00288	2.27604	1.4061	58.08582
59	120	0.00288	2.27604	1.7576	55.86374

Contd table-64

sl no	Ti	Uasp	Up	Pi-air	calTo
60	120	0.00288	2.27604	2.1091	54.1114
61	120	0.00288	2.27604	2.4607	52.67238
62	120	0.00288	2.27604	2.8122	51.45718
63	120	0.00288	2.27604	3.1637	50.40857
64	120	0.00288	2.27604	3.5153	49.48843
65	120	0.00288	2.27604	3.8668	48.67078
66	120	0.00288	2.27604	4.2183	47.93611
67	120	0.00288	2.27604	4.5699	47.2699
68	120	0.00478	2.27604	0.3515	79.47405
69	120	0.00478	2.27604	0.707	70.33483
70	120	0.00478	2.27604	1.0545	65.58704
71	120	0.00478	2.27604	1.4061	62.36941
72	120	0.00478	2.27604	1.7576	59.98346
73	120	0.00478	2.27604	2.1091	58.1019
74	120	0.00478	2.27604	2.4607	56.55676
75	120	0.00478	2.27604	2.8122	55.25194
76	120	0.00478	2.27604	3.1637	54.126
77	120	0.00478	2.27604	3.5153	53.13801
78	120	0.00478	2.27604	3.8668	52.26005
79	120	0.00478	2.27604	4.2183	51.47121
80	120	0.00478	2.27604	4.5699	50.75587
81	120	0.00478	2.27604	4.9214	50.10261
82	120	0.00478	2.27604	5.2729	49.50201
83	120	0.00699	2.27604	0.3515	83.83101
84	120	0.00699	2.27604	0.707	74.19075
85	120	0.00699	2.27604	1.0545	69.18268
86	120	0.00699	2.27604	1.4061	65.78866
87	120	0.00699	2.27604	1.7576	63.2719
88	120	0.00699	2.27604	2.1091	61.28718

Contd table-64

sl no	Ti	Uasp	Up	Pi-air	calTo
89	120	0.00699	2.27604	2.4607	59.65734
90	120	0.00699	2.27604	2.8122	58.28098
91	120	0.00699	2.27604	3.1637	57.09332
92	120	0.00699	2.27604	3.5153	56.05116
93	120	0.00699	2.27604	3.8668	55.12507
94	120	0.00699	2.27604	4.2183	54.29299
95	120	0.00699	2.27604	4.5699	53.53842
96	120	0.00699	2.27604	4.9214	52.84936
97	120	0.00923	2.27604	0.3515	87.16841
98	120	0.00923	2.27604	0.707	77.14437
99	120	0.00923	2.27604	1.0545	71.93692
100	120	0.00923	2.27604	1.4061	68.40777
101	120	0.00923	2.27604	1.7576	65.79082
102	120	0.00923	2.27604	2.1091	63.72709
103	120	0.00923	2.27604	2.4607	62.03236
104	120	0.00923	2.27604	2.8122	60.60121
105	120	0.00923	2.27604	3.1637	59.36627
106	120	0.00923	2.27604	3.5153	58.28262
107	120	0.00923	2.27604	3.8668	57.31966
108	120	0.00923	2.27604	4.2183	56.45445
109	120	0.00923	2.27604	4.5699	55.66985
110	120	0.00923	2.27604	4.9214	54.95335
111	120	0.0113	2.27604	0.3515	89.681
112	120	0.0113	2.27604	0.707	79.36802
113	120	0.0113	2.27604	1.0545	74.01047
114	120	0.0113	2.27604	1.4061	70.37959
115	120	0.0113	2.27604	1.7576	67.68722
116	120	0.0113	2.27604	2.1091	65.564
117	120	0.0113	2.27604	2.4607	63.82042
118	120	0.0113	2.27604	2.8122	62.34801

Contd table-64

sl no	Ti	Uasp	Up	Pi-air	calTo
118	120	0.0113	2.27604	2.8122	62.34801
119	120	0.0113	2.27604	3.1637	61.07747
120	120	0.0113	2.27604	3.5153	59.96259
121	120	0.0113	2.27604	3.8668	58.97188
122	120	0.0113	2.27604	4.2183	58.08172
123	120	0.0113	2.27604	4.5699	57.2745
124	120	0.0113	2.27604	4.9214	56.53736
125	120	0.013	2.27604	0.3515	91.46359
126	120	0.013	2.27604	0.707	80.94562
127	120	0.013	2.27604	1.0545	75.48158
128	120	0.013	2.27604	1.4061	71.77853
129	120	0.013	2.27604	1.7576	69.03264
130	120	0.013	2.27604	2.1091	66.86721
131	120	0.013	2.27604	2.4607	65.08898
132	120	0.013	2.27604	2.8122	63.58731
133	120	0.013	2.27604	3.1637	62.29151
134	120	0.013	2.27604	3.5153	61.15446
135	120	0.013	2.27604	3.8668	60.14406
136	120	0.013	2.27604	4.2183	59.23621
137	120	0.013	2.27604	4.5699	58.41295
138	120	0.013	2.27604	4.9214	57.66115

Table-65: A sample of target data set-1

Sl.no	Cal To	Sl.no	Cal To	Sl.no	Cal To	Sl.no	Cal To
1	59.61582	35	60.46704	69	59.60952	103	59.61744
2	59.616	36	60.4674	70	59.61096	104	59.61906
3	59.61654	37	60.46794	71	59.61258	105	59.6205
4	59.6169	38	60.46812	72	59.6142	106	59.62212
5	59.61726	39	60.46866	73	59.61582	107	59.62374
6	59.61762	40	60.46902	74	59.61744	108	59.62536
7	59.8986	41	60.46974	75	59.61888	109	59.62698
8	59.89896	42	60.46992	76	59.6205	110	59.62842
9	59.89932	43	59.6079	77	59.62212	111	59.6079
10	59.89986	44	59.60952	78	59.62374	112	59.60952
11	59.90004	45	59.61096	79	59.62536	113	59.61114
12	59.90058	46	59.61258	80	59.62698	114	59.61258
13	59.90094	47	59.6142	81	59.62842	115	59.6142
14	59.9013	48	59.61582	82	59.63004	116	59.61582
15	59.90184	49	59.61744	83	59.6079	117	59.61744
16	59.9022	50	59.61888	84	59.60952	118	59.61906
17	59.90274	51	59.6205	85	59.61096	119	59.6205
18	59.9031	52	59.62212	86	59.61258	120	59.62212
19	60.18192	53	59.62374	87	59.6142	121	59.62374
20	60.18228	54	59.62536	88	59.61582	122	59.62536
21	60.18264	55	59.6079	89	59.61744	123	59.62698
22	60.18318	56	59.60952	90	59.61906	124	59.62842
23	60.18336	57	59.61096	91	59.6205	125	59.6079
24	60.1839	58	59.61258	92	59.62212	126	59.60952
25	60.18426	59	59.6142	93	59.62374	127	59.61114
26	60.18462	60	59.61582	94	59.62536	128	59.61258
27	60.18516	61	59.61744	95	59.62698	129	59.6142
28	60.18534	62	59.61888	96	59.62842	130	59.61582
29	60.18606	63	59.6205	97	59.6079	131	59.61744
30	60.18624	64	59.62212	98	59.60952	132	59.61906
31	60.4656	65	59.62374	99	59.61096	133	59.6205
32	60.46578	66	59.62536	100	59.61258	134	59.62212
33	60.46632	67	59.62698	101	59.6142	135	59.62374
34	60.46668	68	59.6079	102	59.61582	136	59.62536
						137	59.62698
						138	59.62842

Table-66: A sample of testing data set-2

sl.no.	Ti	Uasp	Up	Cs	Pi-air	Ms	Tocal
1	120	0.00478	2.279604	0.1	2.10919	132.13	51.92784
2	140	0.00478	2.279604	0.1	2.10919	132.13	58.65452
3	160	0.00478	2.279604	0.1	2.10919	132.13	65.18183
4	180	0.00478	2.279604	0.1	2.10919	132.13	71.5397
5	120	0.00923	2.279604	0.1	2.10919	132.13	59.33442
6	120	0.013	2.279604	0.1	2.10919	132.13	63.59841
7	120	0.017	2.279604	0.1	2.10919	132.13	67.15121
8	120	0.00478	3.214336	0.1	2.10919	132.13	47.99749
9	120	0.00478	3.985914	0.1	2.10919	132.13	45.68953
10	120	0.00478	5.315932	0.1	2.10919	132.13	42.77337
11	120	0.00478	2.279604	0.2	2.10919	132.13	49.62842
12	120	0.00478	2.279604	0.3	2.10919	132.13	48.33085
13	120	0.00478	2.279604	0.4	2.10919	132.13	47.43083
14	120	0.00478	2.279604	0.1	2.8122	132.13	49.63765
15	120	0.00478	2.279604	0.1	3.51532	132.13	47.93077
16	120	0.00478	2.279604	0.1	4.2183	132.13	46.58007
17	120	0.00478	2.279604	0.1	2.10919	142.04	52.40285
18	120	0.00478	2.279604	0.1	2.10919	58.54	46.86903
19	120	0.00478	2.279604	0.1	2.10919	182.17	54.07061

Table-67: A sample of target data set-2

Sl.no	Cal To	Sl.no	Cal To
1	43.51374	10	43.49412
2	46.14804	11	43.51644
3	48.8682	12	43.51896
4	51.66612	13	43.52166
5	43.51392	14	43.50834
6	43.51392	15	43.50294
7	43.5141	16	43.49736
8	43.5078	17	42.90858
9	43.50276	18	48.15828
		19	40.51386

Table-68: A sample of testing data set-3

sl.no	Ti	Uasp	Up	Cs	Pi-air	Ms	Ycal
1	120	0.00478	2.279604	0.1	2.10919	132.13	67.26828
2	140	0.00478	2.279604	0.1	2.10919	132.13	65.69746
3	160	0.00478	2.279604	0.1	2.10919	132.13	64.36643
4	180	0.00478	2.279604	0.1	2.10919	132.13	63.21478
5	120	0.00923	2.279604	0.1	2.10919	132.13	63.34319
6	120	0.013	2.279604	0.1	2.10919	132.13	61.39172
7	120	0.017	2.279604	0.1	2.10919	132.13	59.90527
8	120	0.00478	3.214336	0.1	2.10919	132.13	53.52461
9	120	0.00478	3.985914	0.1	2.10919	132.13	46.38816
10	120	0.00478	5.315932	0.1	2.10919	132.13	38.30303
11	120	0.00478	2.279604	0.2	2.10919	132.13	70.4163
12	120	0.00478	2.279604	0.3	2.10919	132.13	72.32563
13	120	0.00478	2.279604	0.4	2.10919	132.13	73.71163
14	120	0.00478	2.279604	0.1	2.8122	132.13	62.56791
15	120	0.00478	2.279604	0.1	3.51532	132.13	59.1489
16	120	0.00478	2.279604	0.1	4.2183	132.13	56.49503
17	120	0.00478	2.279604	0.1	2.10919	142.04	67.08566
18	120	0.00478	2.279604	0.1	2.10919	58.54	69.35849
19	120	0.00478	2.279604	0.1	2.10919	182.17	66.46112

Table-69: A sample of target data set-3

Sl.no	Cal Y	Sl.no	Cal Y
1	63.37206	11	63.3744
2	64.82034	12	63.37674
3	66.2778	13	63.37908
4	67.74318	14	63.39654
5	63.37224	15	63.42084
6	63.37224	16	63.44514
7	63.37242	17	63.27972
8	63.37548	18	64.04634
9	63.37836	19	62.90298
10	63.38322		

SEM Photographs, FTIR plots, TGA&DTA Graphs and Graphs for Individual Exponents

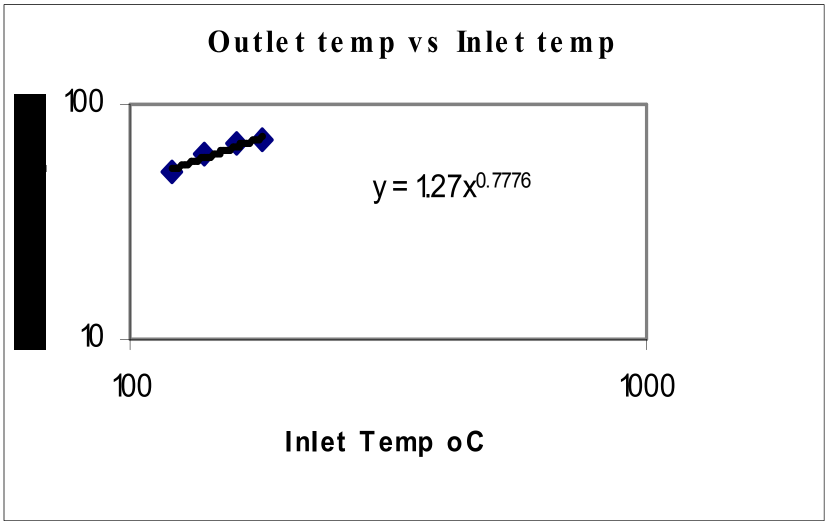


Figure-22

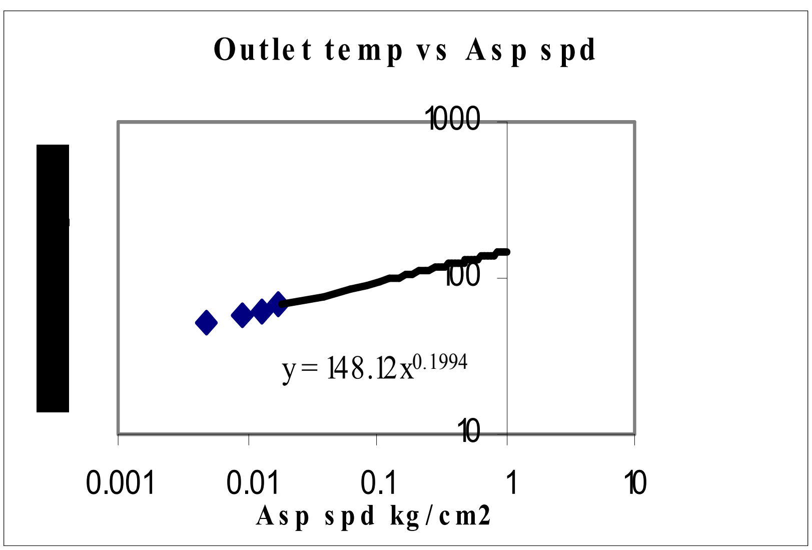


Figure-23

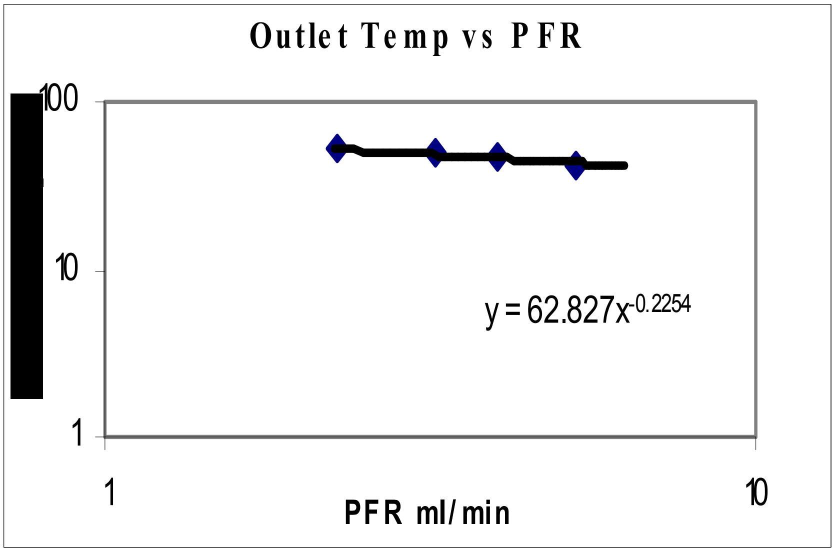


Figure-24

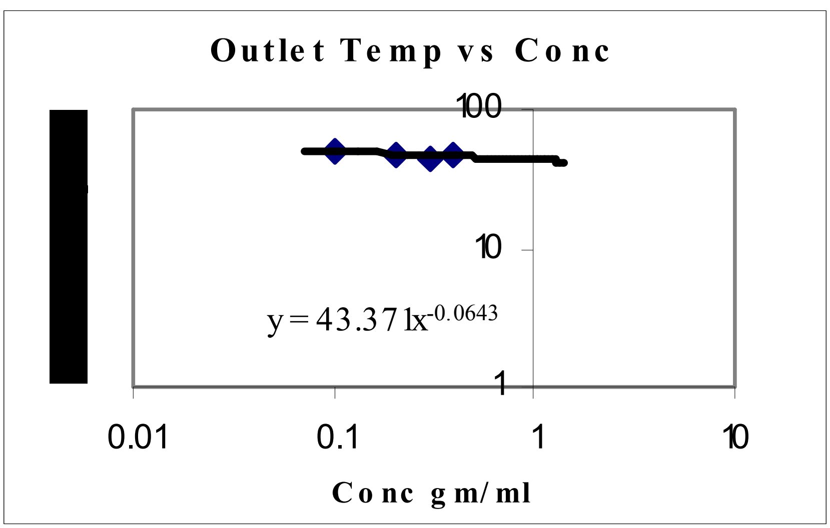


Figure-25

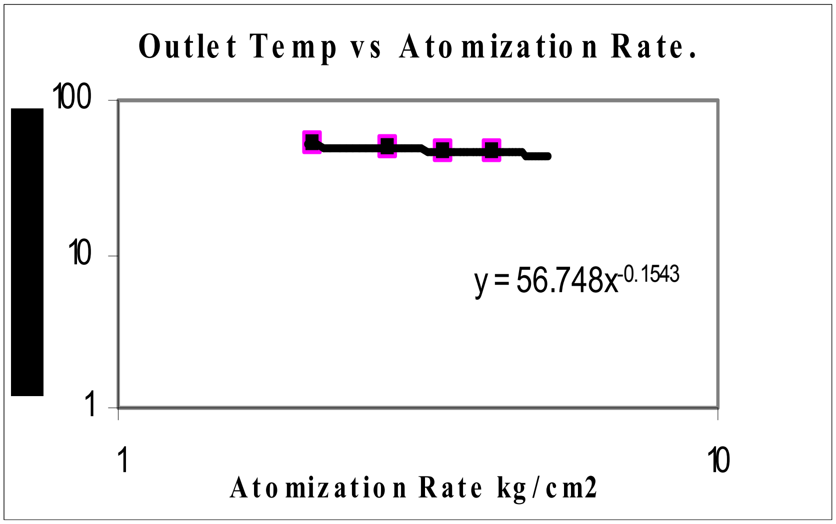


Figure-26

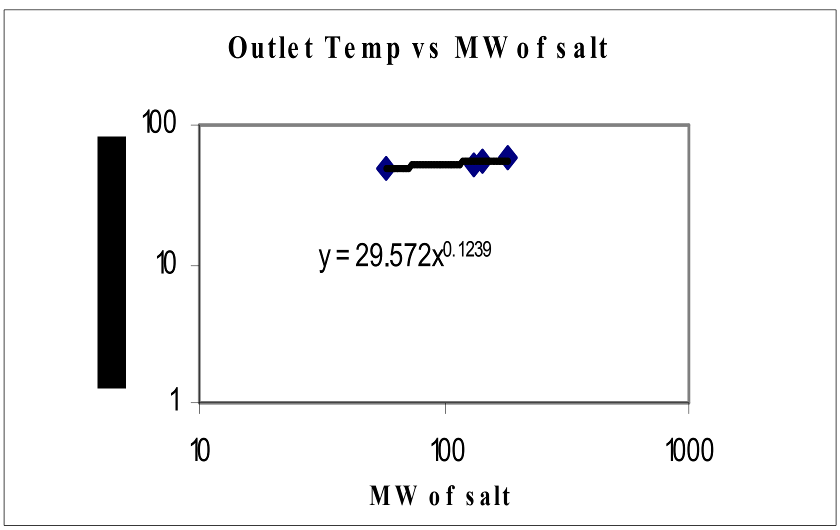


Figure-27

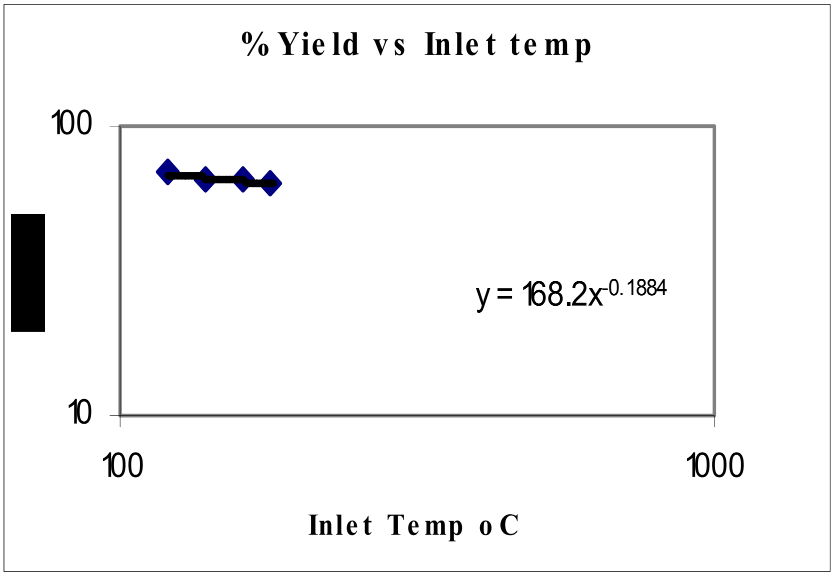


Figure-28

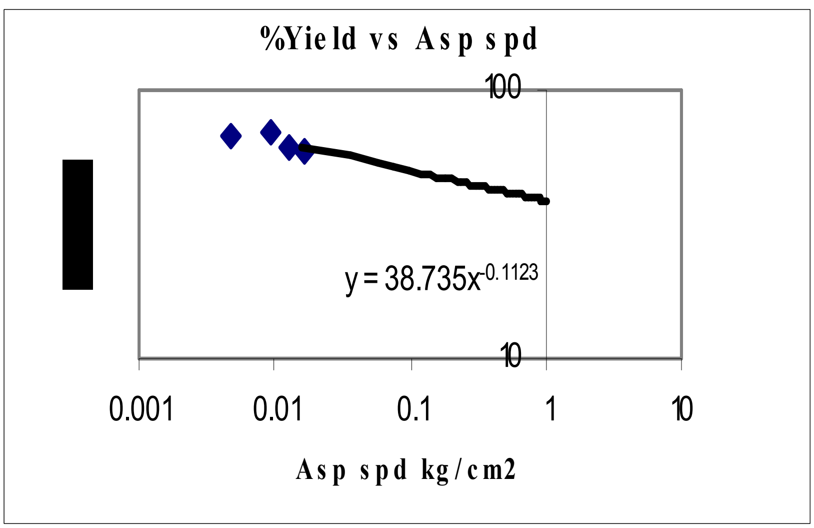


Figure-29

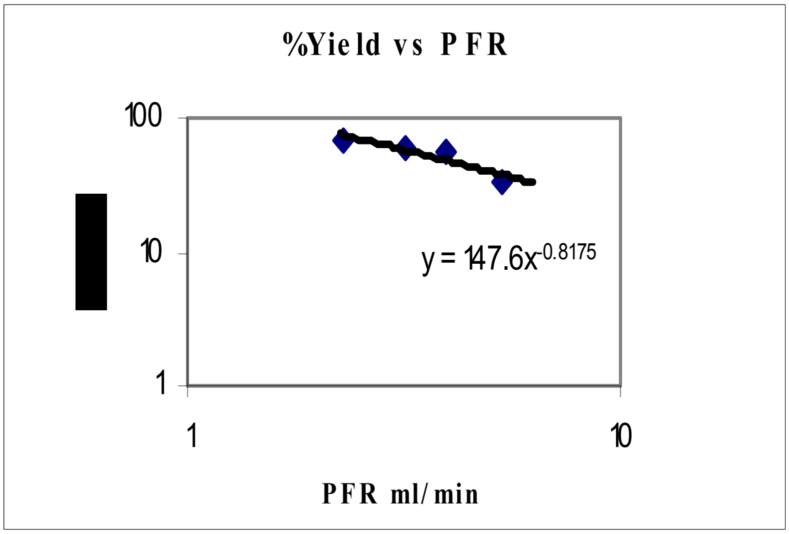


Figure-30

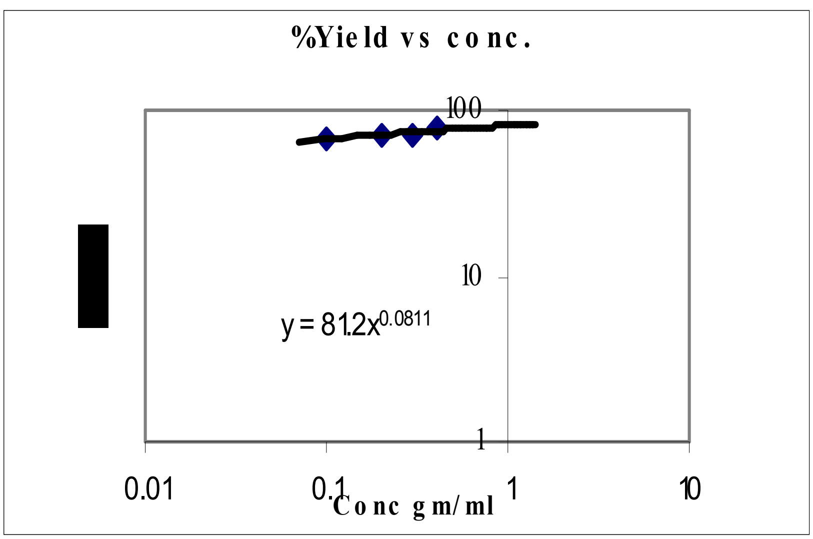


Figure-31

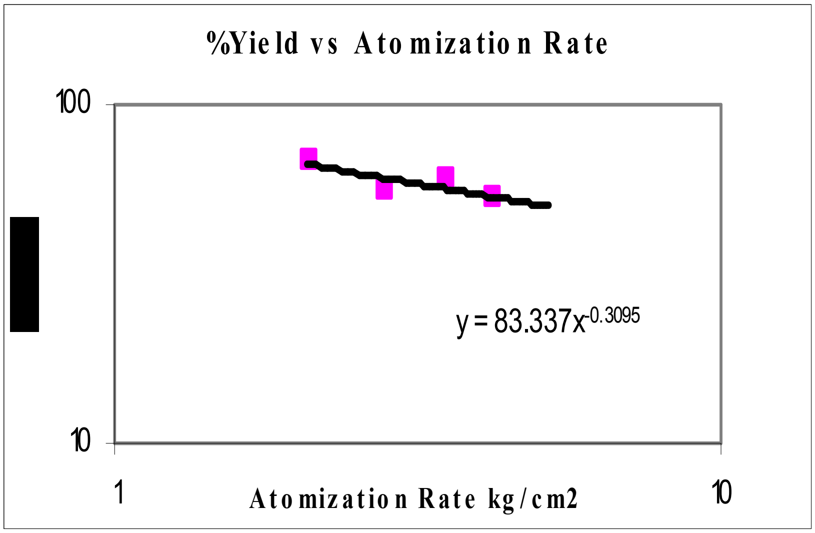


Figure-32

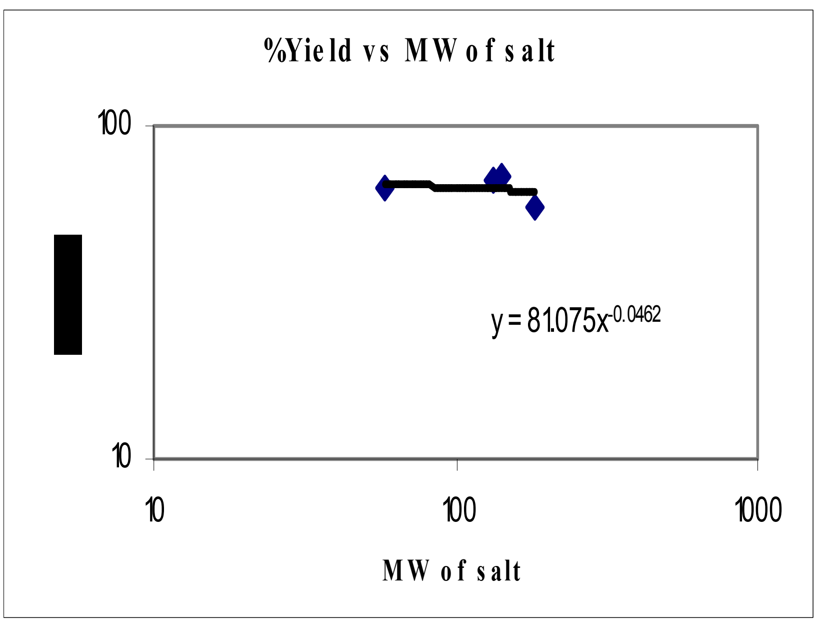


Figure-33

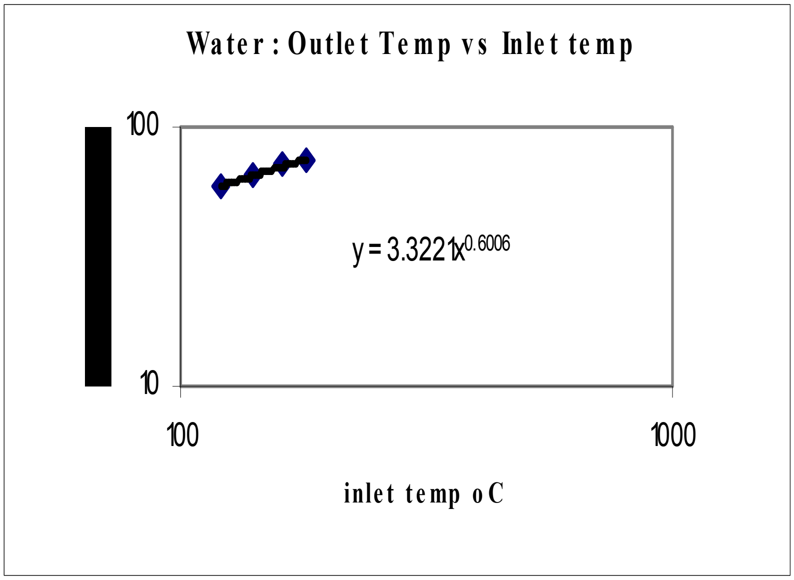


Figure-34

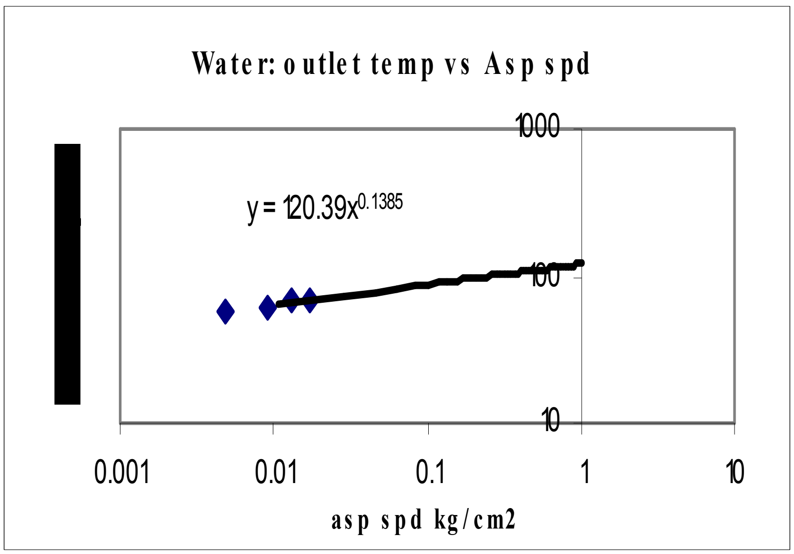


Figure-35

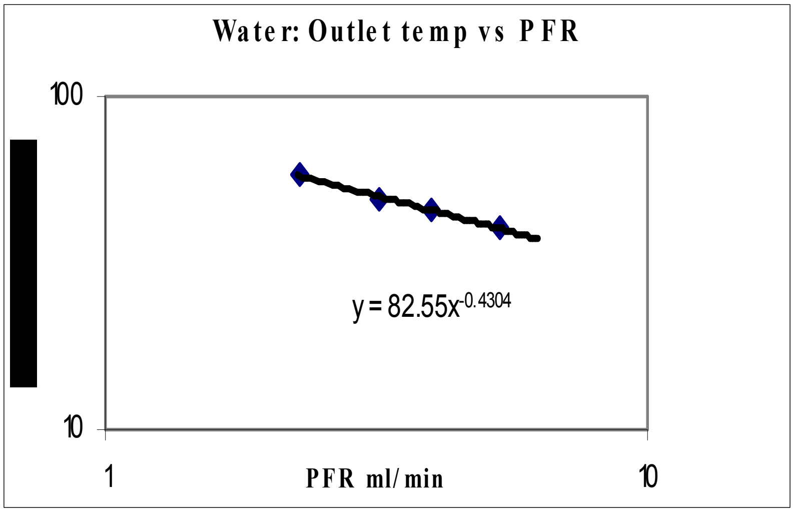


Figure-36

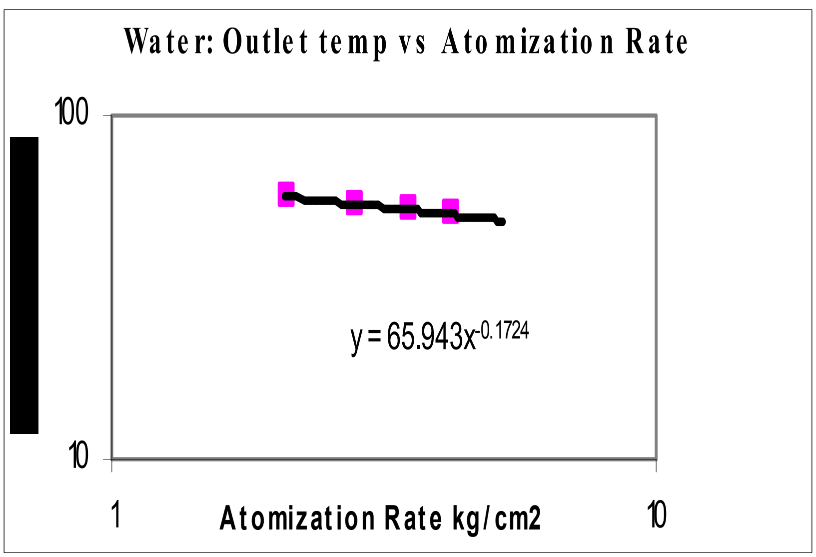


Figure-37

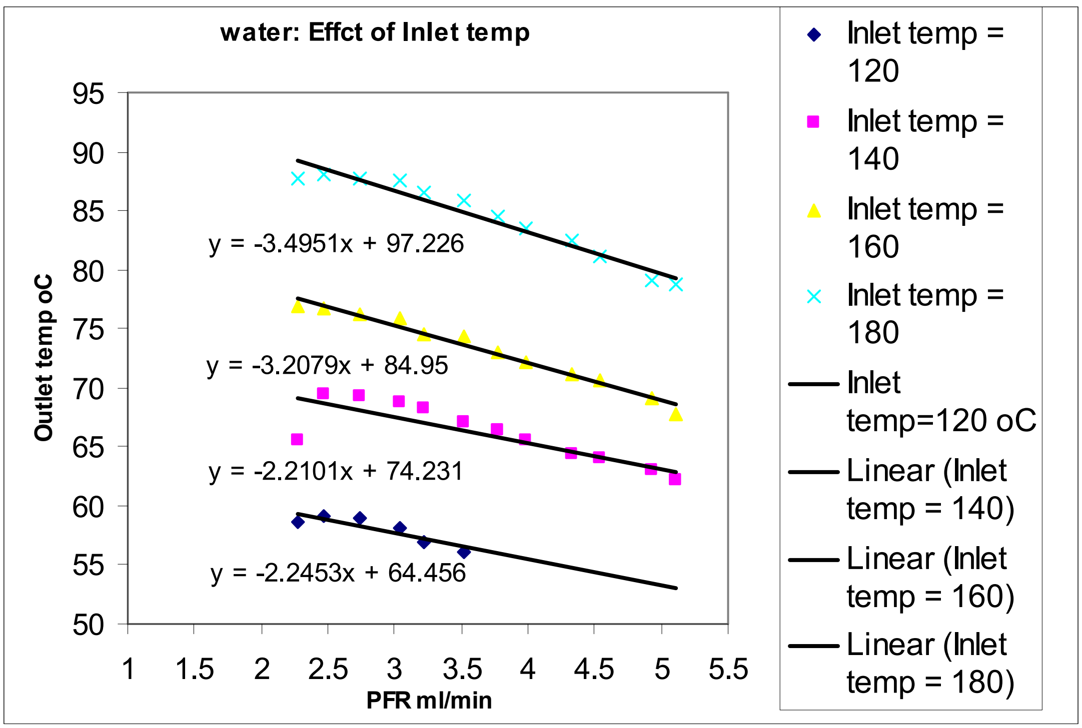

water: Effct of Inlet temp
Outlet temp oC
PFR ml/min
95
90
85
80
75
70
65
60
55
50
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
y = -3.4951x + 97.226
y = -3.2079x + 84.95
y = -2.2101x + 74.231
y = -2.2453x + 64.456
Inlet temp = 120
Inlet temp = 140
Inlet temp = 160
Inlet temp = 180
Inlet temp=120 oC
Linear (Inlet temp = 140)
Linear (Inlet temp = 160)
Linear (Inlet temp = 180)

Figure-38

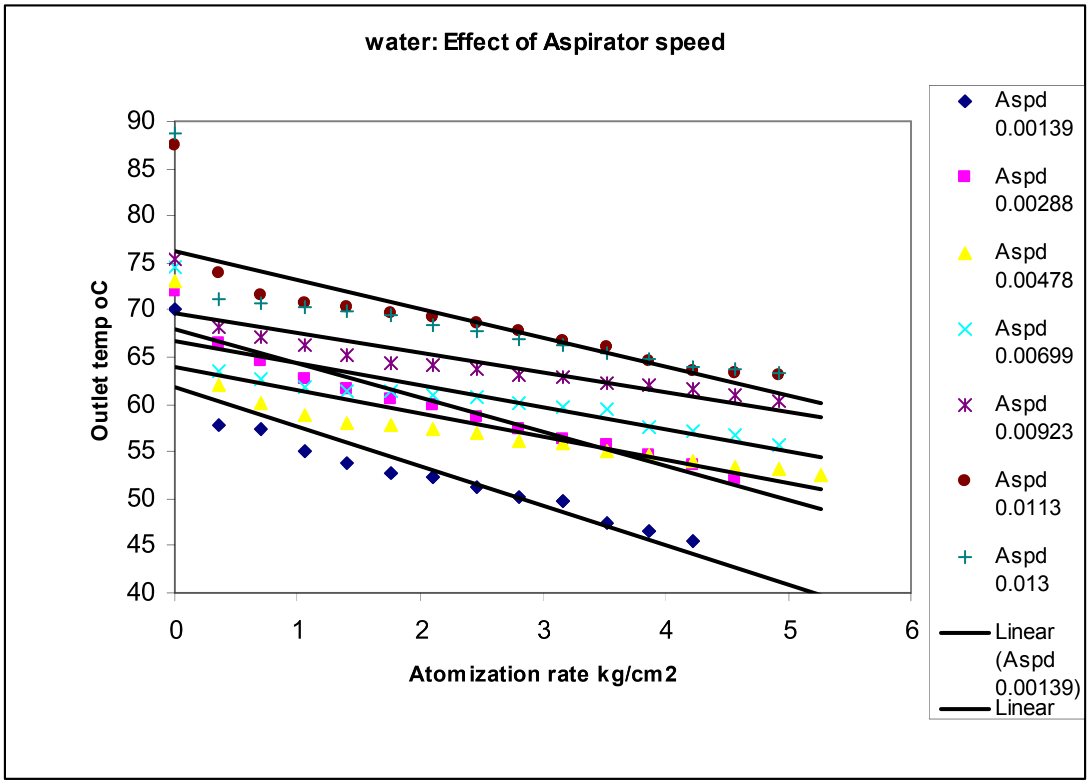

water: Effect of Aspirator speed
Outlet temp oC
Atomization rate kg/cm2
90
85
80
75
70
65
60
55
50
45
40
0
1
2
3
4
5
6
Aspd 0.00139
Aspd 0.00288
Aspd 0.00478
Aspd 0.00699
Aspd 0.00923
Aspd 0.0113
Aspd 0.013
Linear (Aspd 0.00139)
Linear

Figure-39

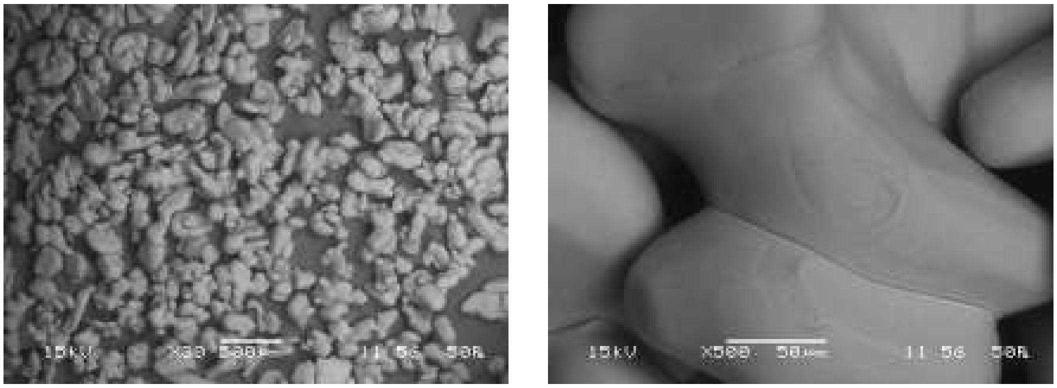


Figure 45: Ammonium sulfate before spray drying

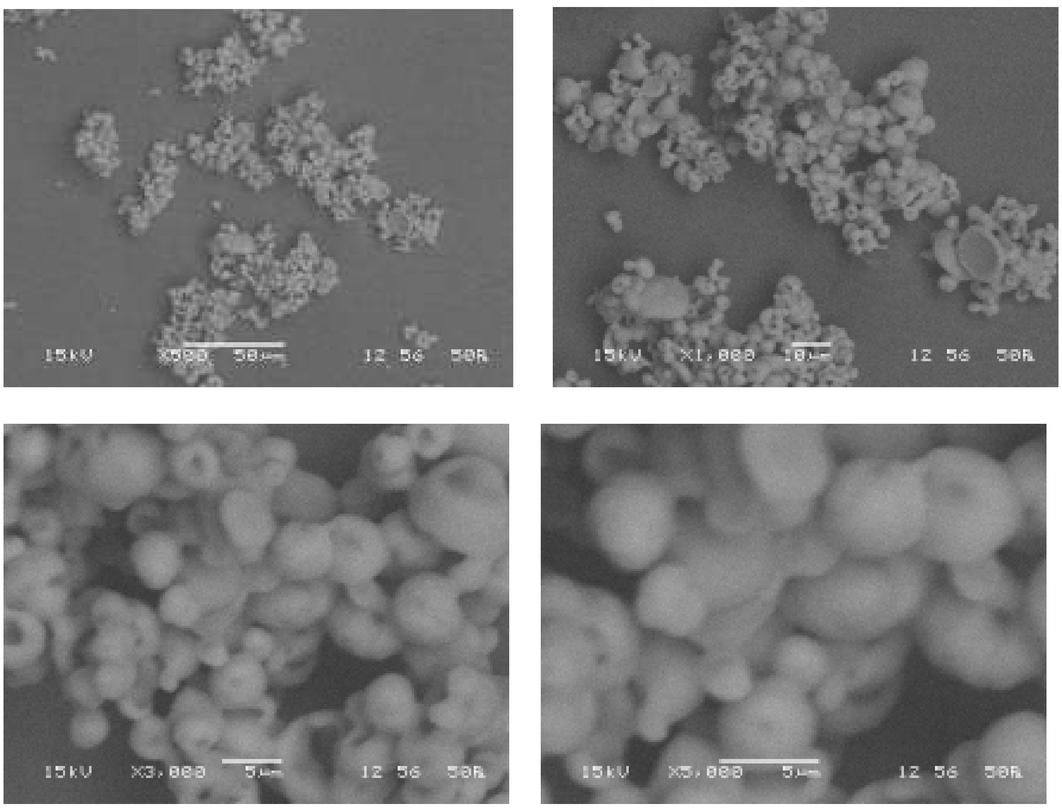


Figure 46 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

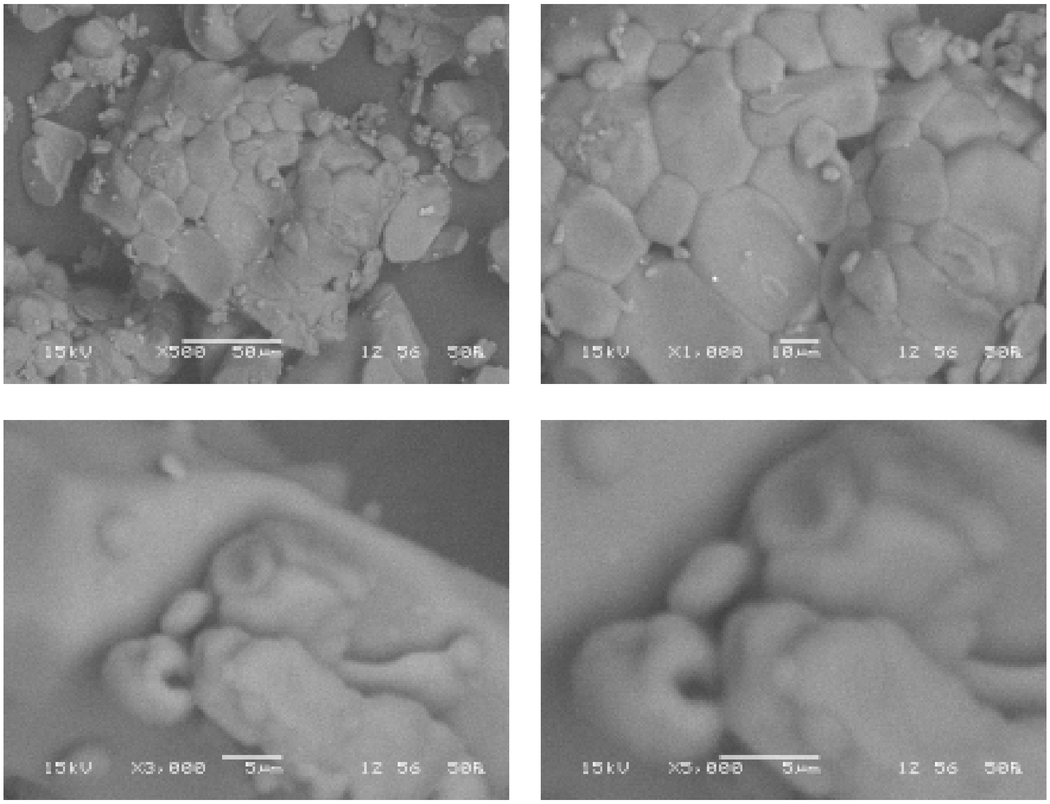


Figure 47 (Spray dried Ammonium sulfate collected in the drying chamber operated at IT= 120 ^{o}C, Aspd = 0.00478 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2}

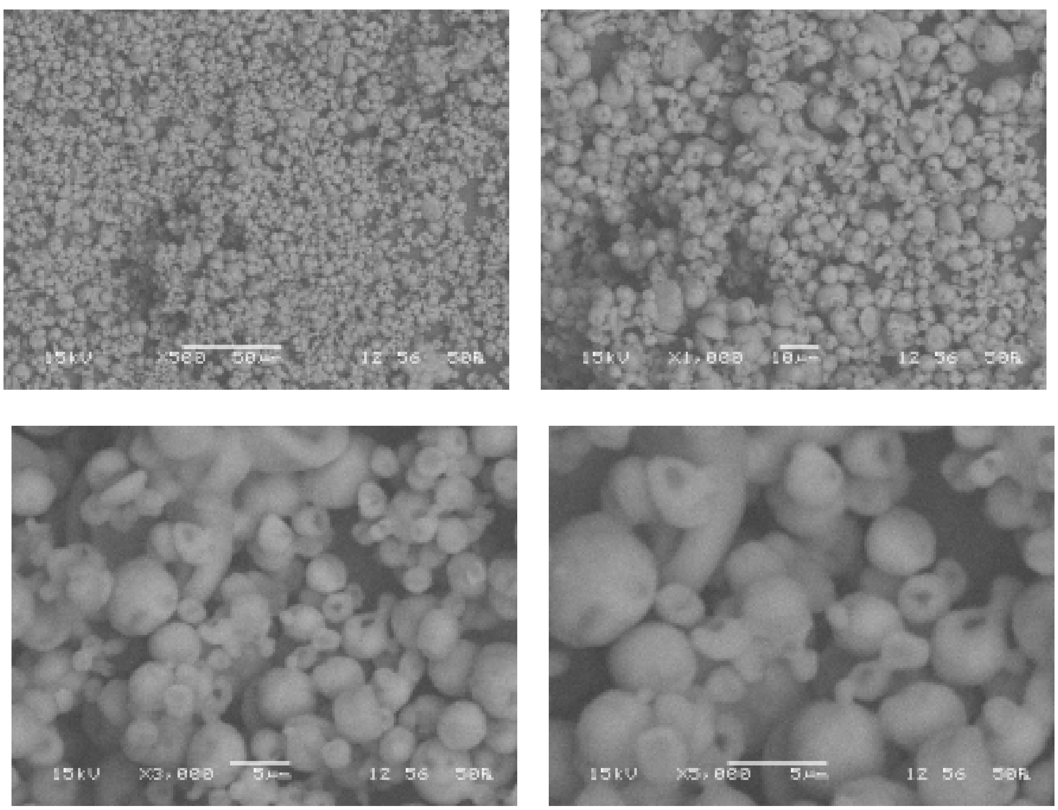


Figure 48 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.00923 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

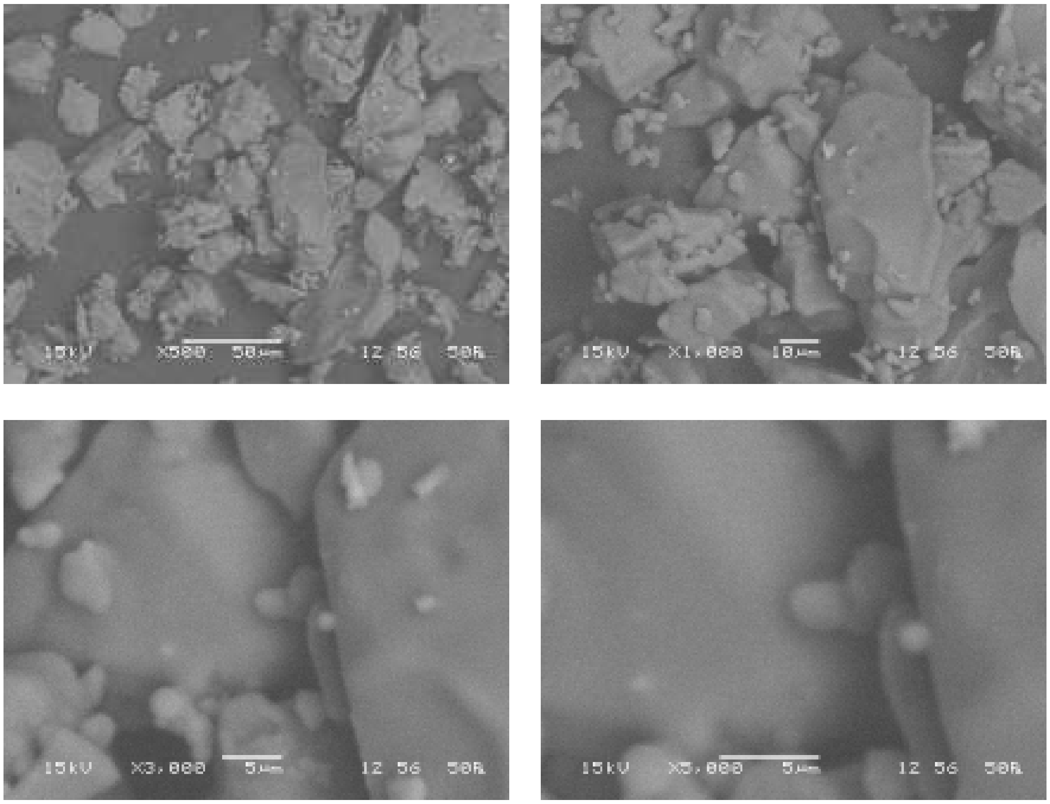


Figure 49 (Spray dried Ammonium sulfate collected in the drying chamber operated at IT= 120 ^{o}C, Aspd = 0.00923 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

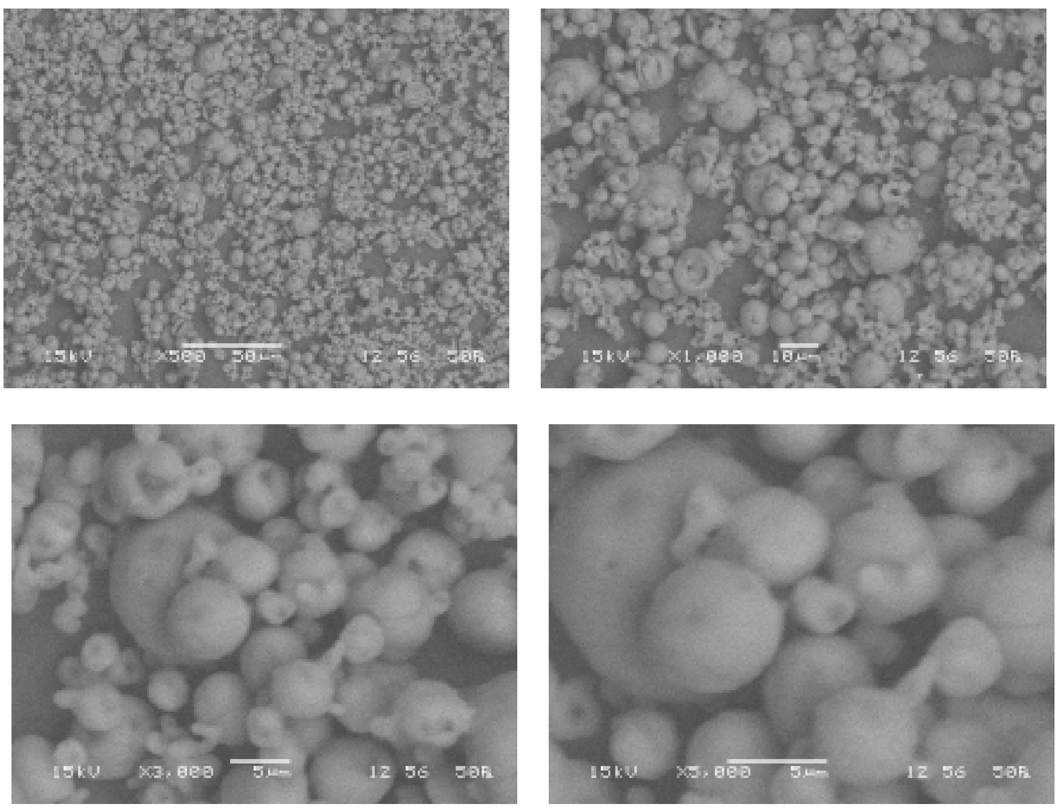


Figure 50 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.013 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

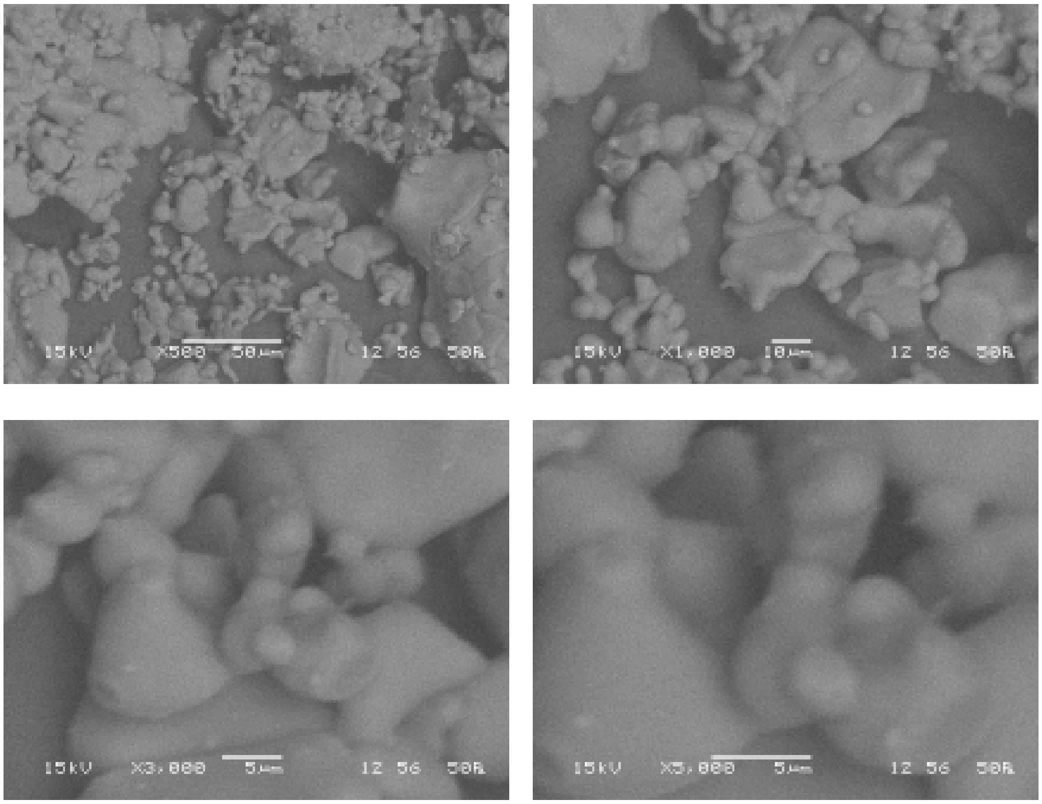


Figure 51 (Spray dried Ammonium sulfate collected in the drying chamber operated at IT= 120 ^{o}C, Aspd = 0.013 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

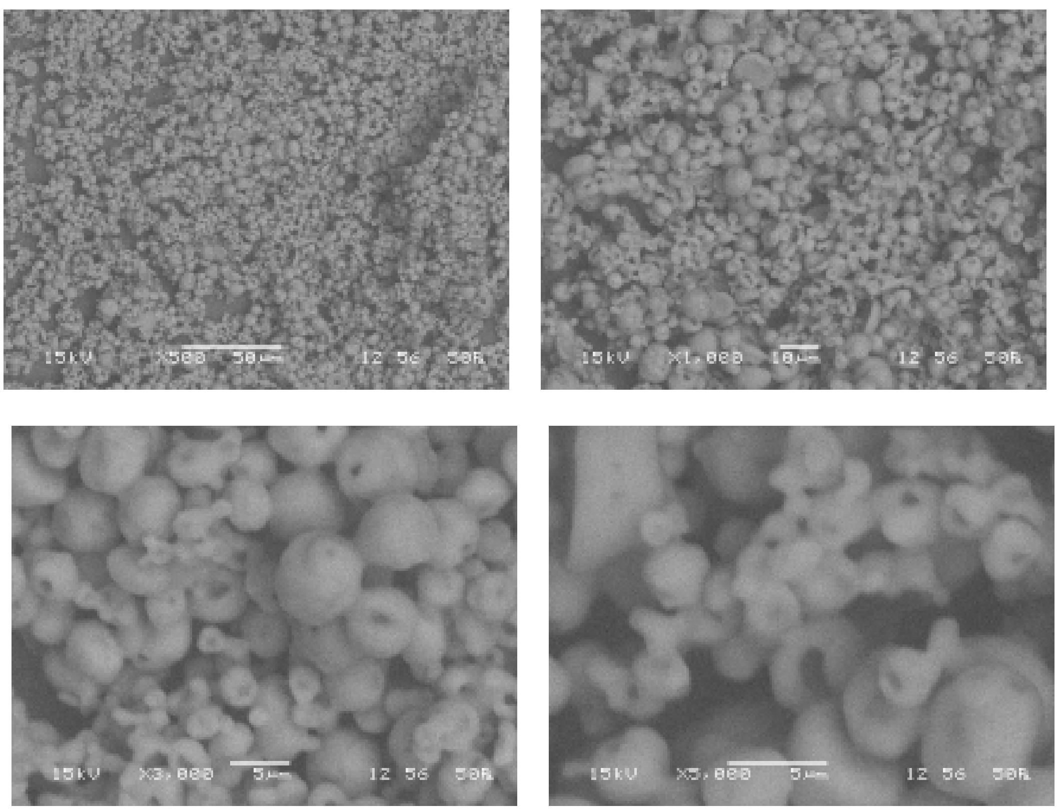


Figure 52 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.017 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

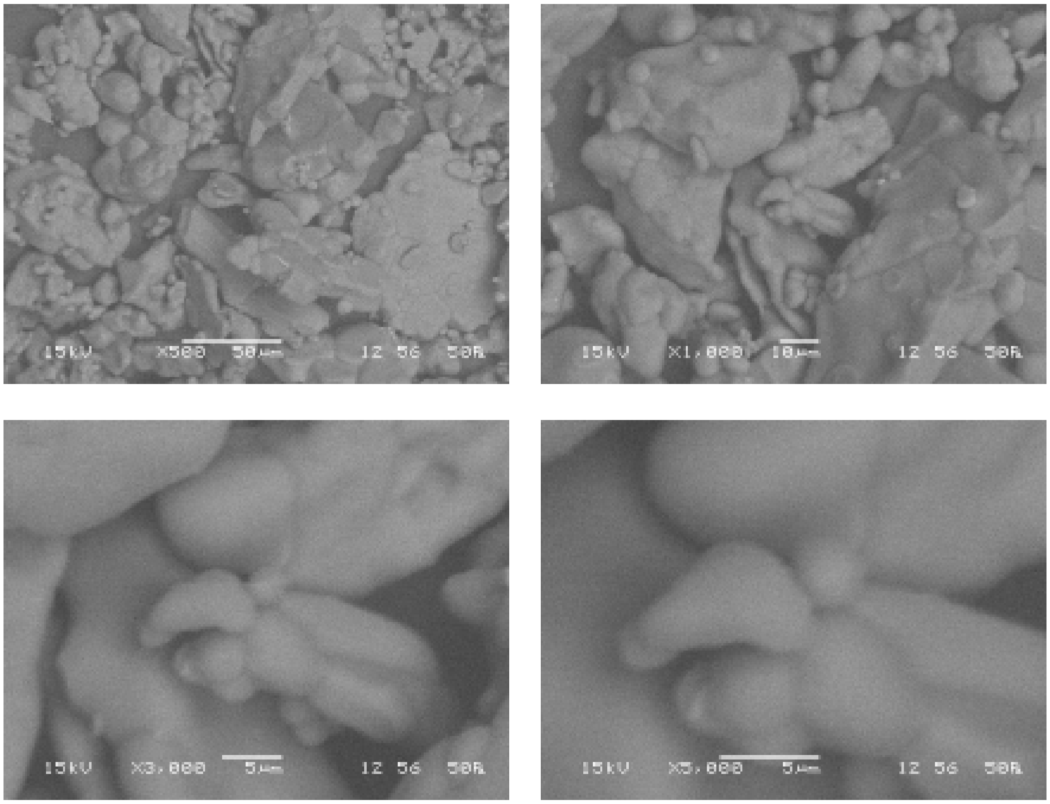


Figure 53 (Spray dried Ammonium sulfate collected in the drying chamber operated at IT= 120 ^{o}C, Aspd = 0.017 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

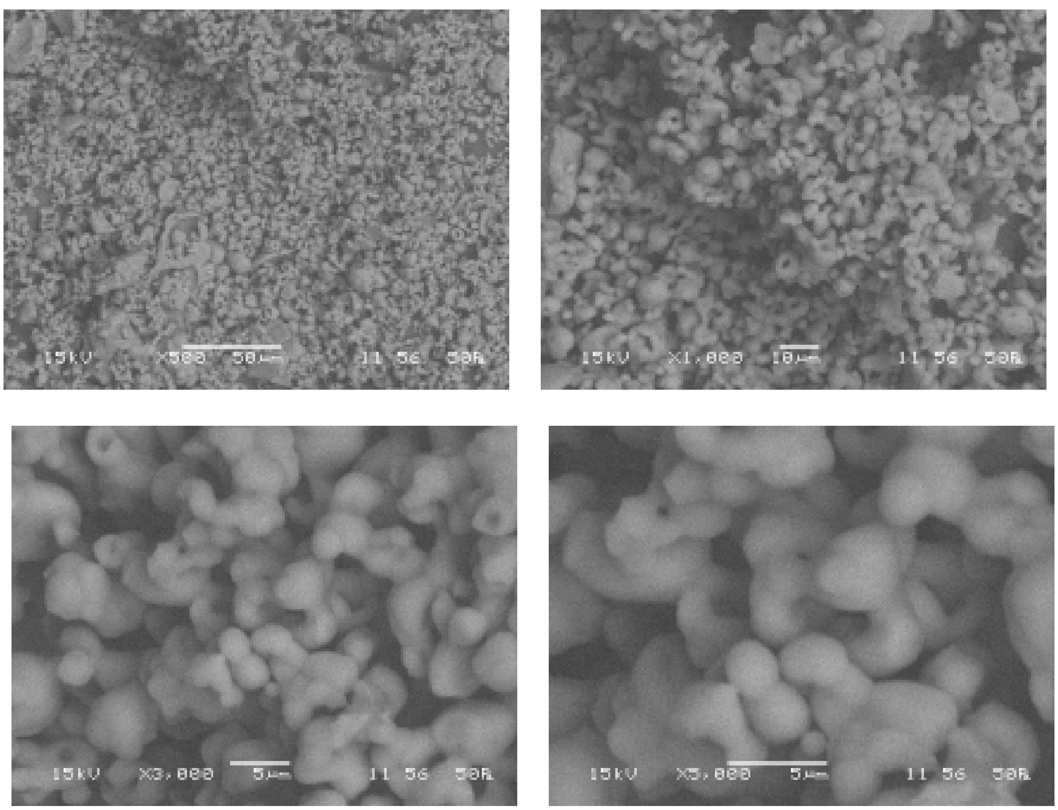


Figure 54 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 140 ^{o}C, Aspd = 0.00478 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

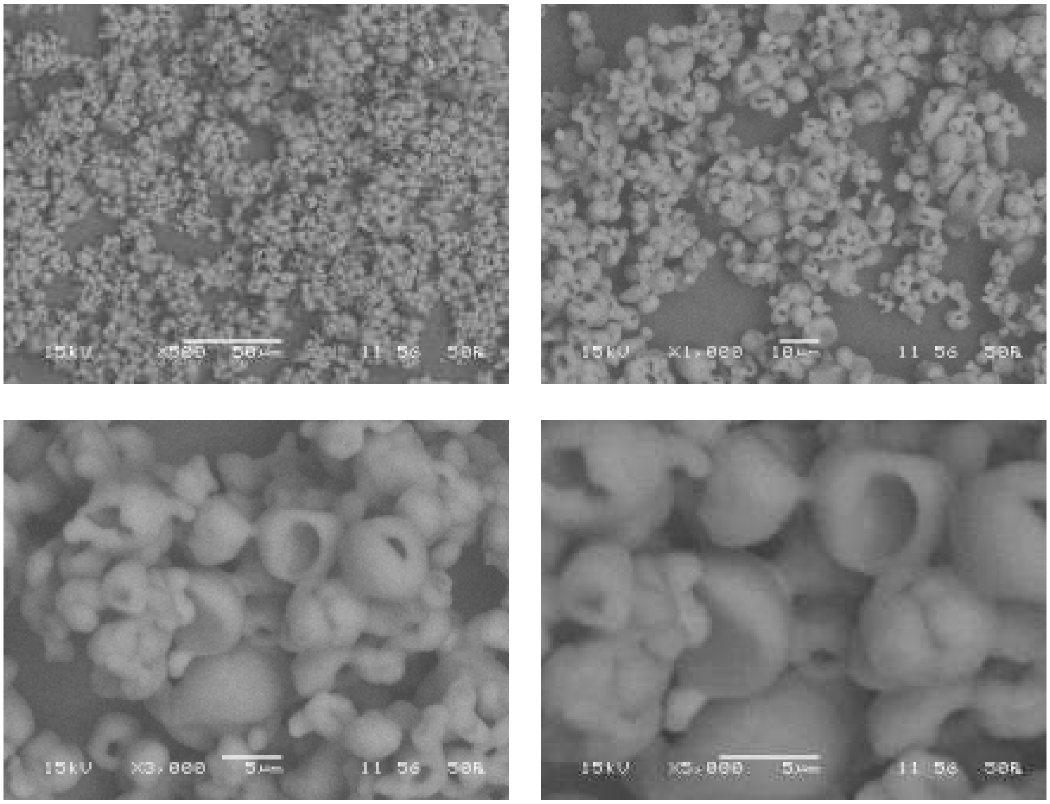


Figure 55 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 160 ^{o}C, Aspd = 0.00478 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

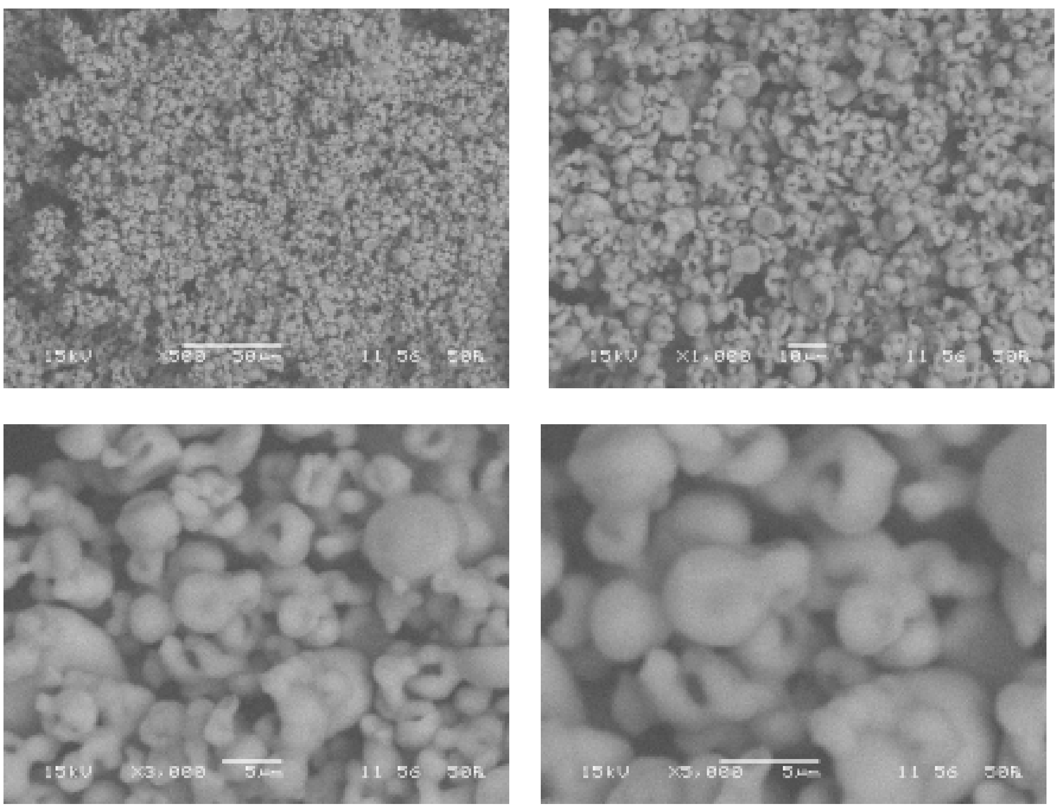


Figure 56 (Spray dried Ammonium sulfate collected in the cyclone separator operated at IT= 180 ^{o}C, Aspd = 0.00478 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

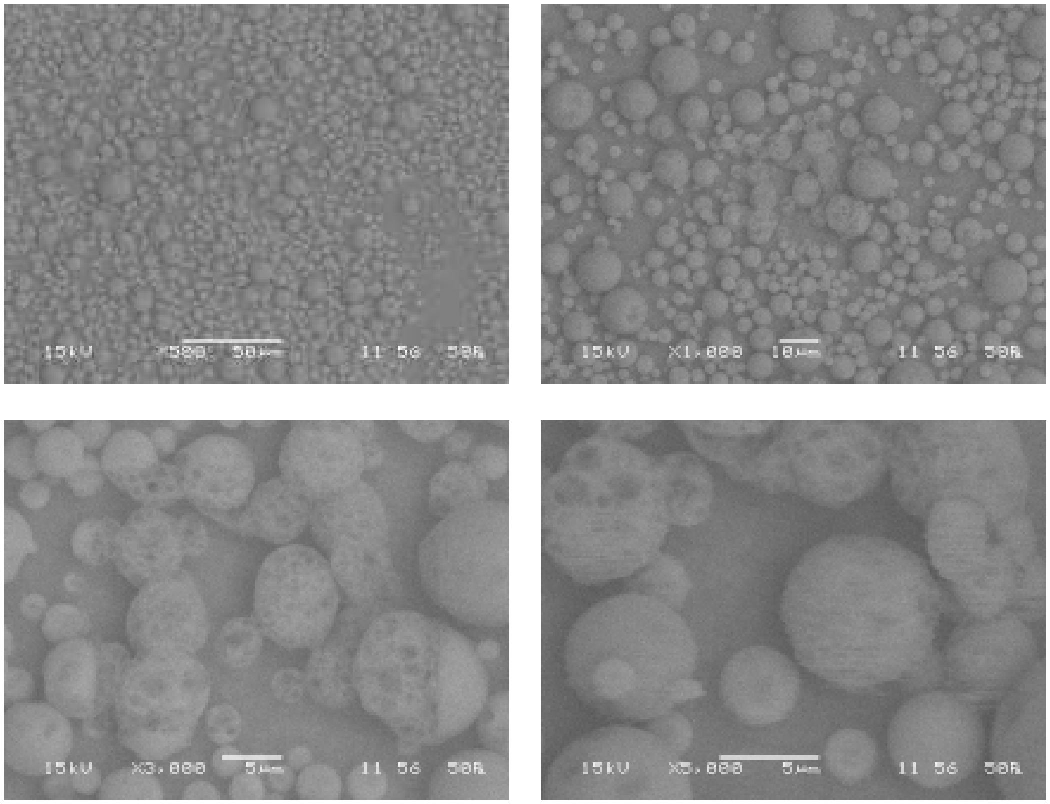


Figure 57 (Spray dried mixture of Mannitol and maltodextrin (1:1)collected in the cyclone separator operated at IT= 120 ^oC, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

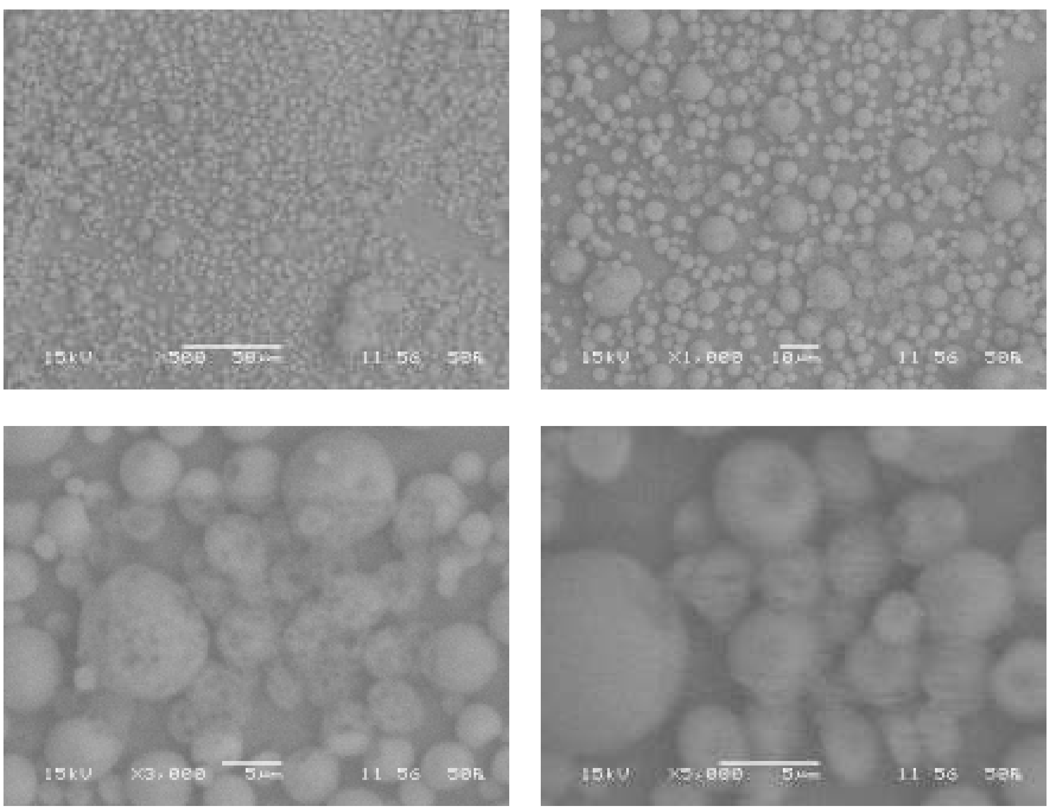


Figure 58 (Spray dried mixture of Mannitol and maltodextrin (1:3)collected in the cyclone separator operated at IT= 120 ^oC, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

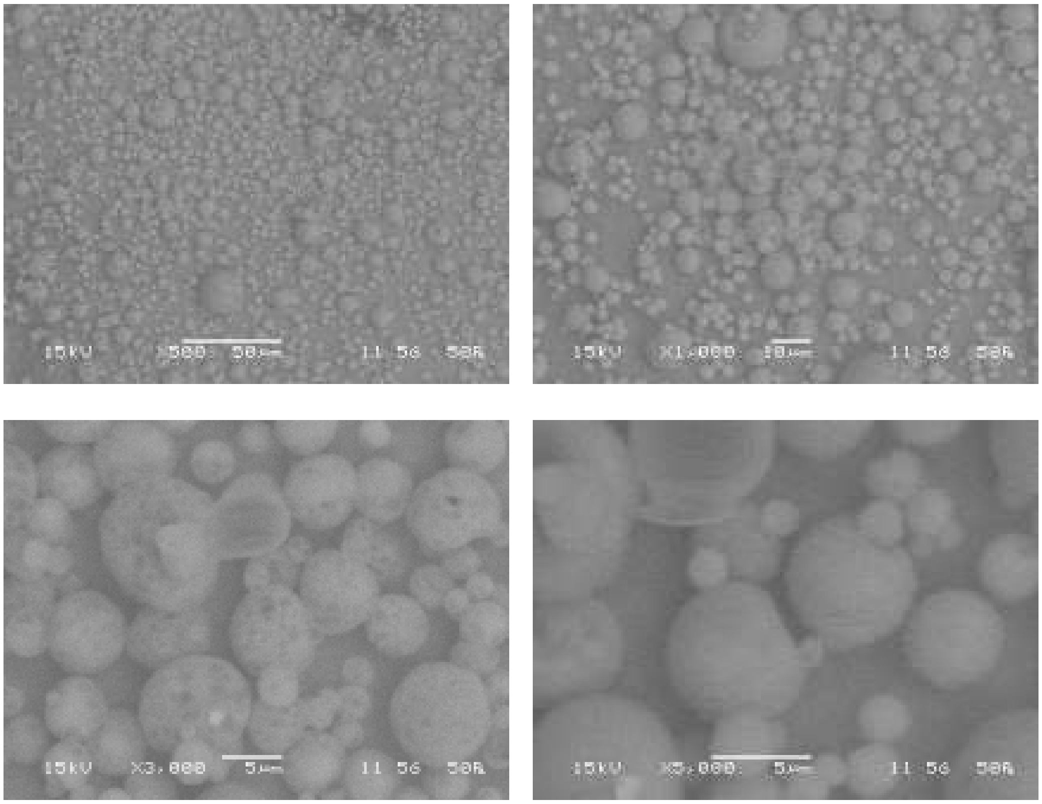


Figure 59 (Spray dried mixture of Mannitol and maltodextrin (1:5)collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

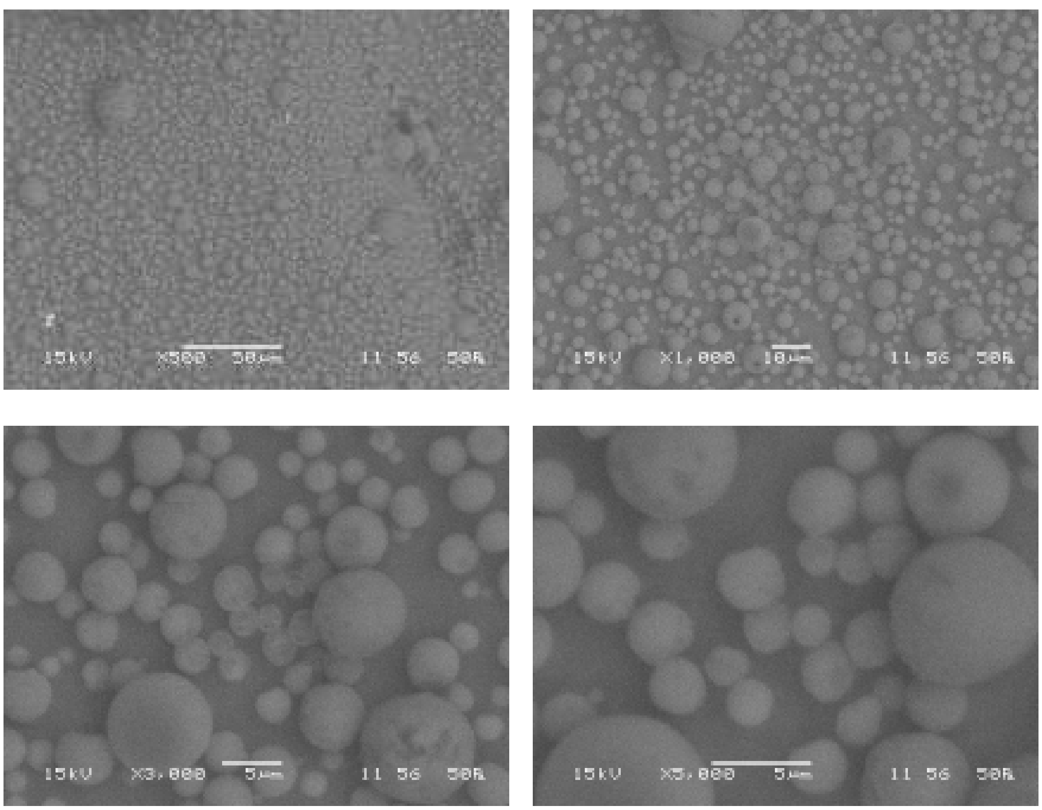


Figure 60 (Spray dried mixture of Mannitol and maltodextrin (1:7)collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

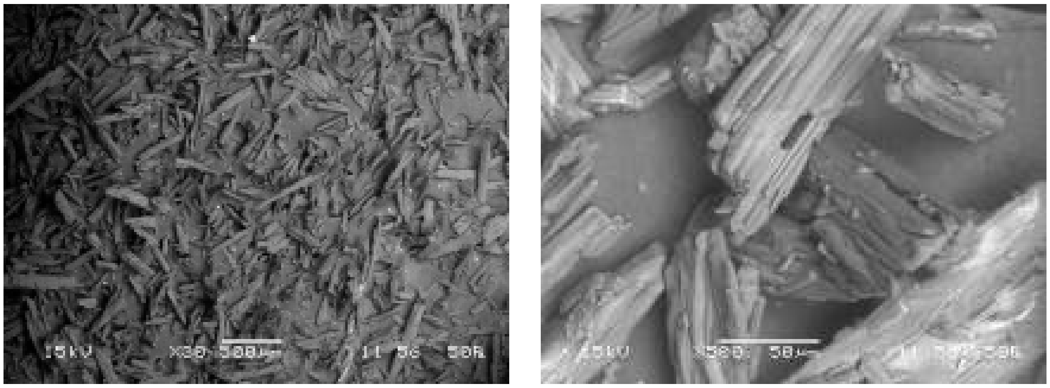


Figure 61 : Mannitol before spray drying

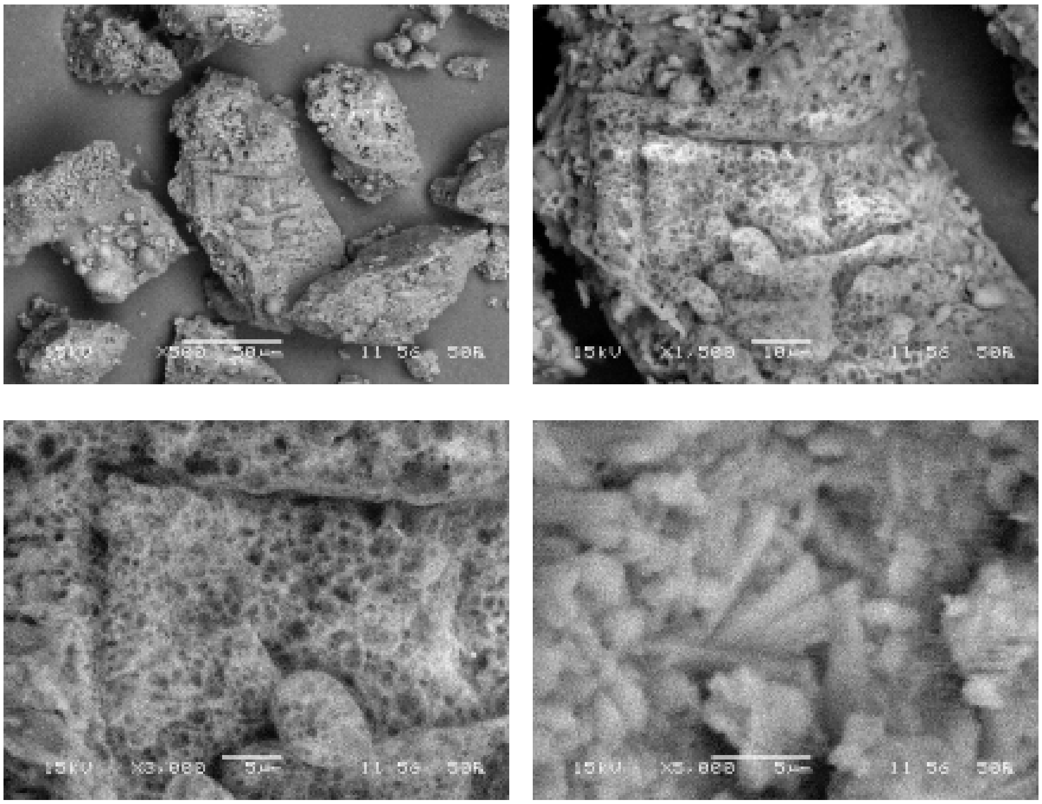


Figure 62 (Spray dried mixture of Mannitol collected in the cyclone separator operated at IT= 120 ^oC, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

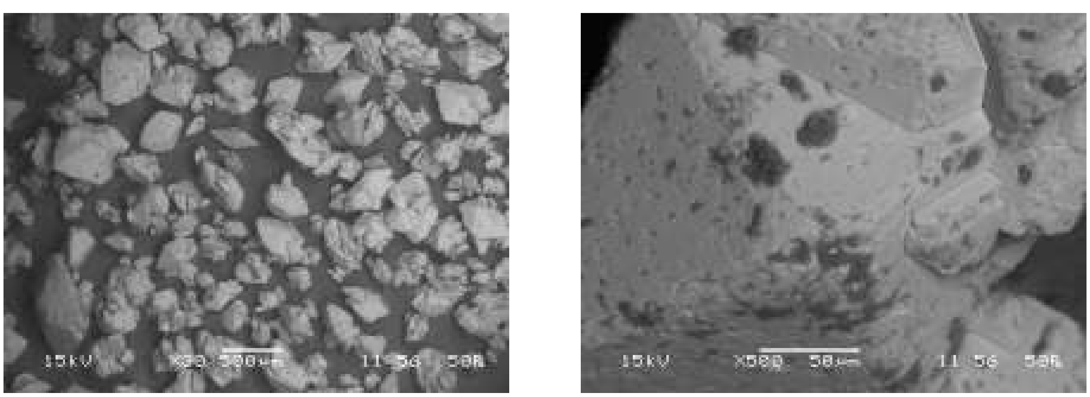


Figure 63 :Na_2SO_4 before spray drying.

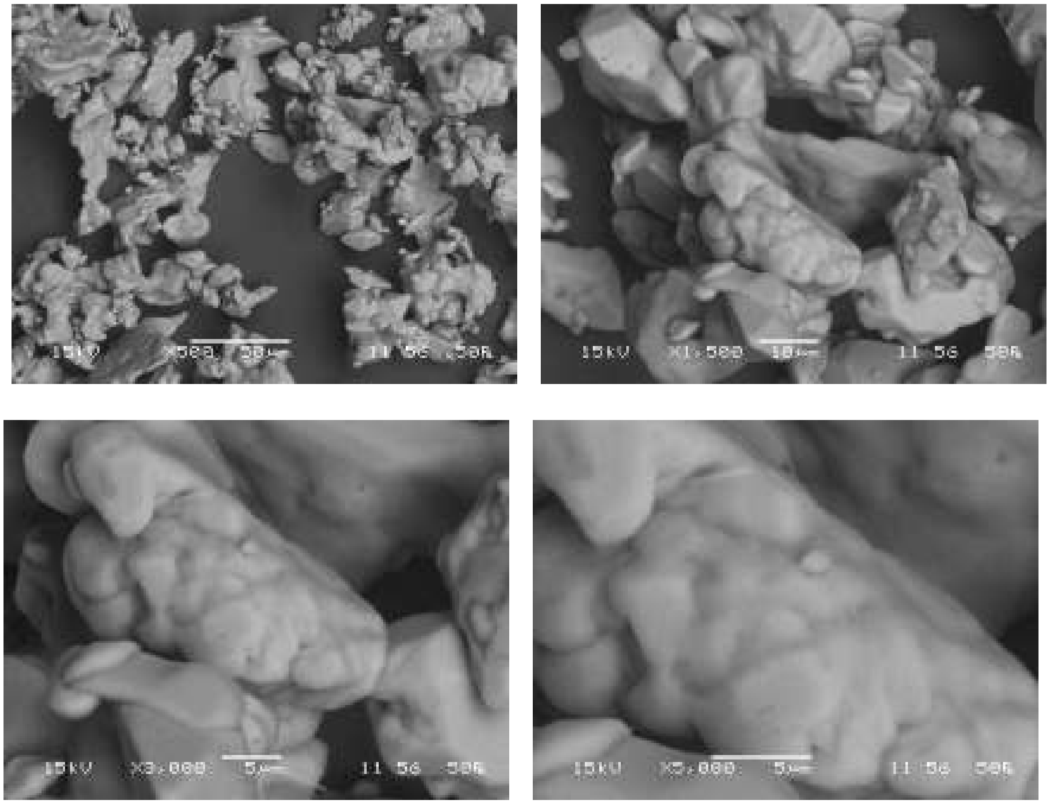


Figure 64 (Spray dried mixture of Na_2SO_4 collected in the cyclone separator operated at IT= 120 ^oC, Aspd = 0.00478 kg/cm^2, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^2)

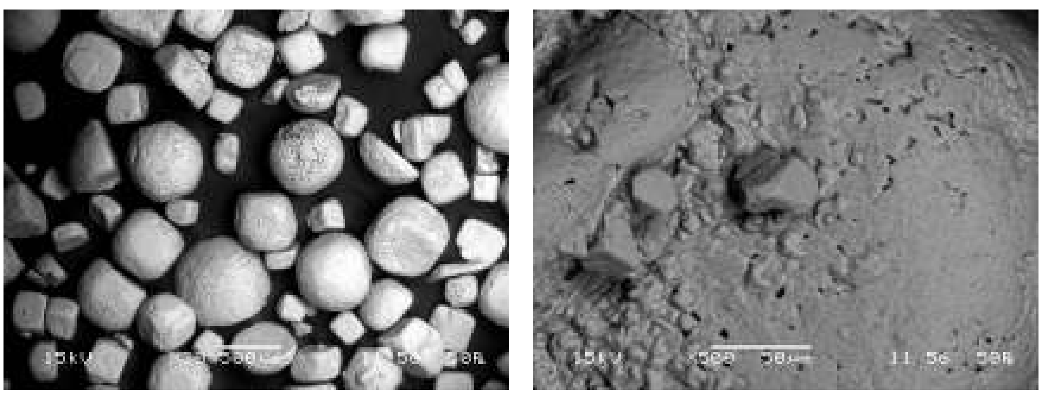


Figure 65 :NaCl before spray drying.

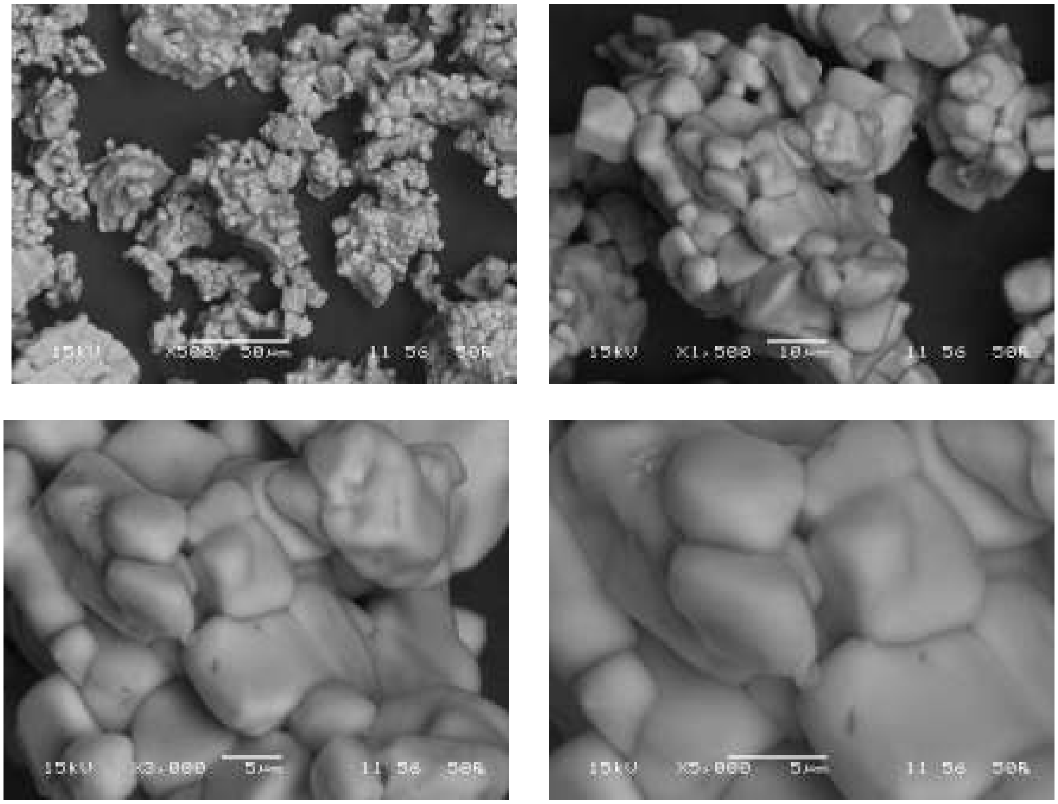


Figure 66 (Spray dried mixture of NaCl collected in the cyclone separator operated at IT= 120 ^{o}C, Aspd = 0.00478 kg/cm^{2}, PFR = 2.279604 ml/min, conc = 1gm/ml, Atomization rate = 2.10919 kg/cm^{2})

FTIR report of NaCl before drying

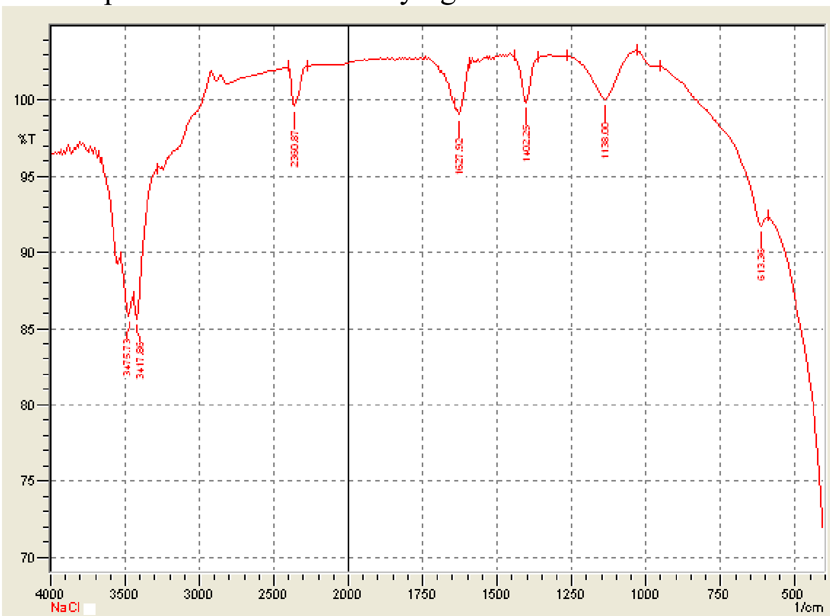


Figure 67

FTIR report of NaCl after drying

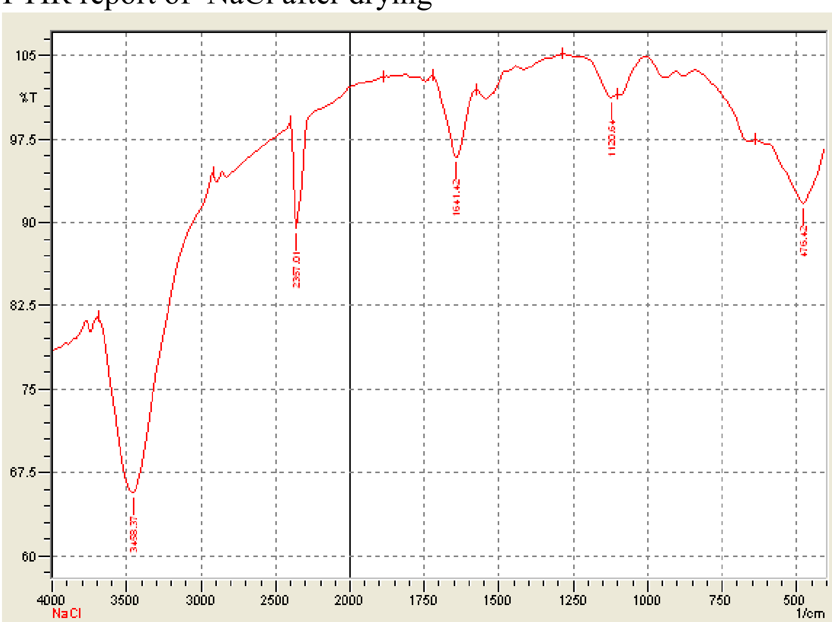


Figure 68

FTIR report of Mannitol before drying

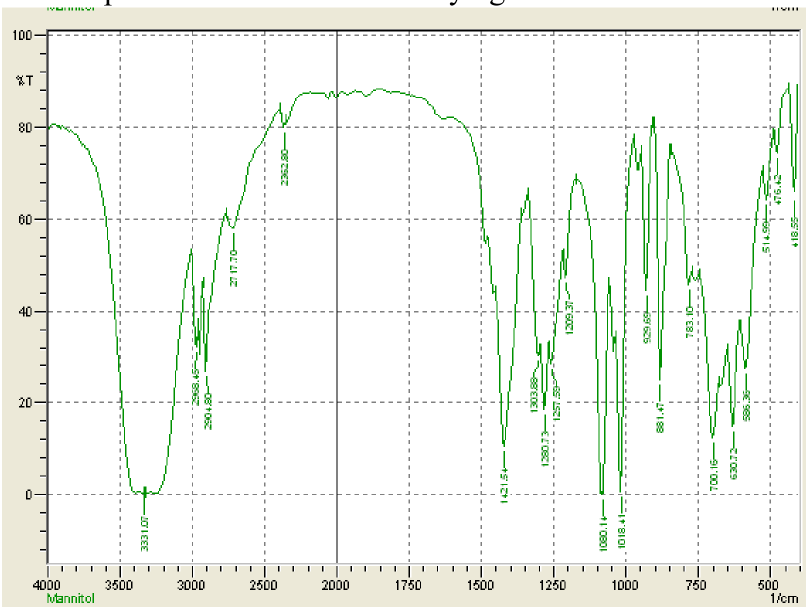


Figure 69

FTIR report of Mannitol after drying

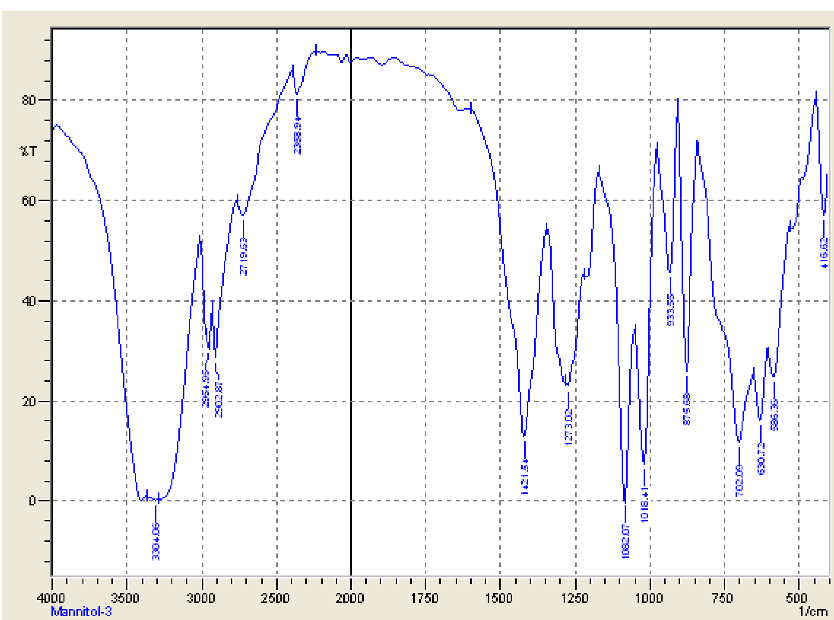


Figure 70

FTIR report of Na_2 SO_4 before drying

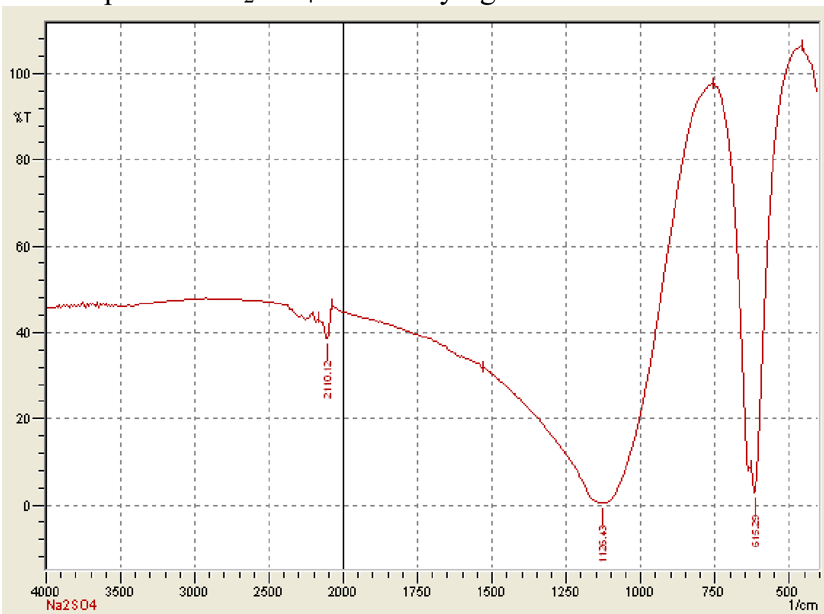


Figure 71

FTIR report of Na_2 SO_4 after drying

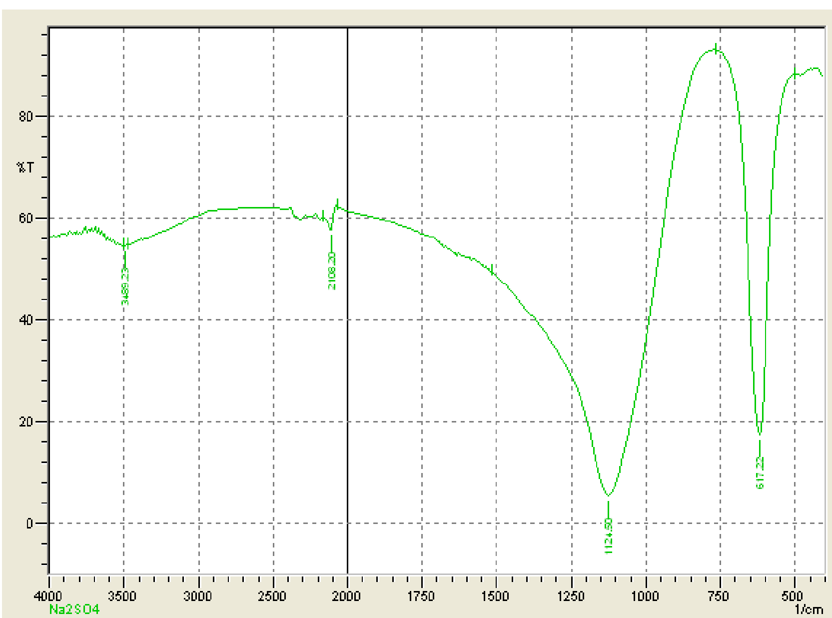
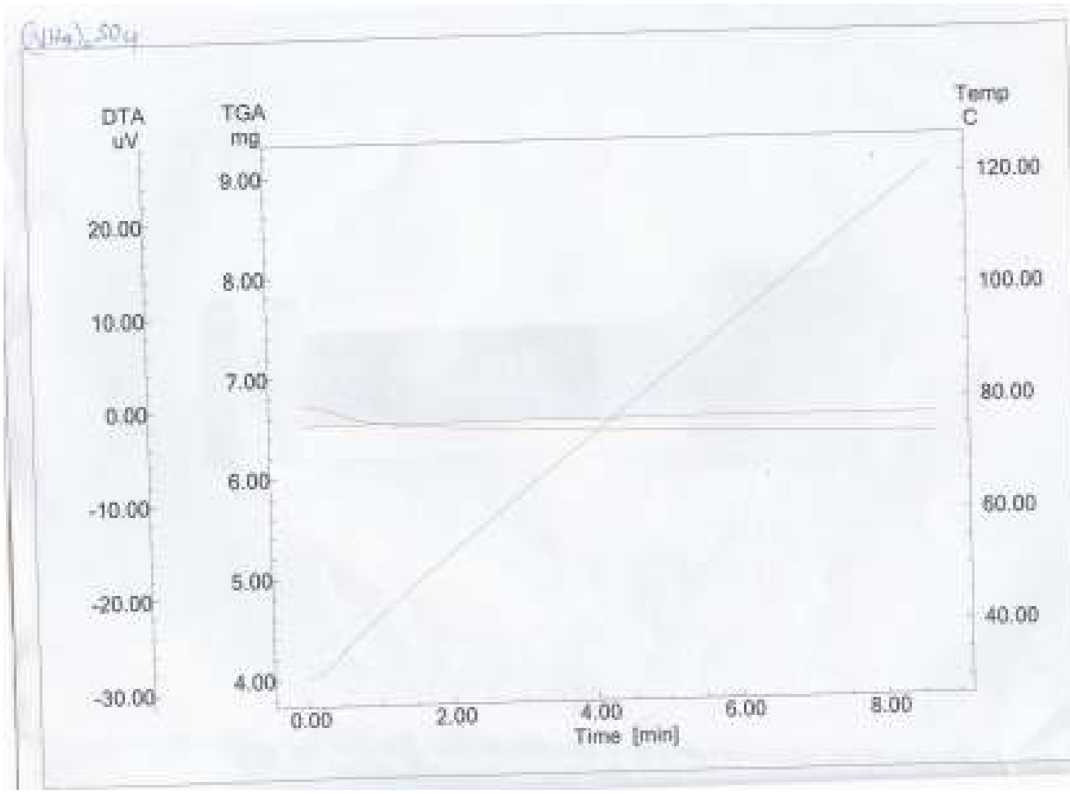
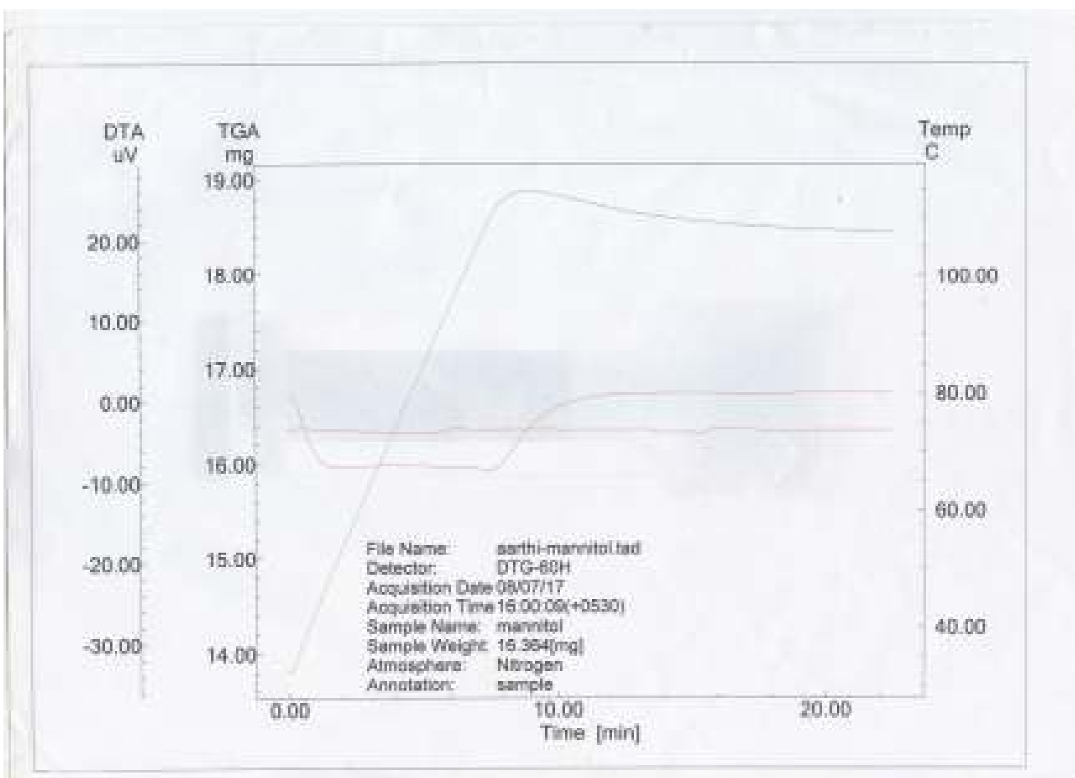


Figure 72

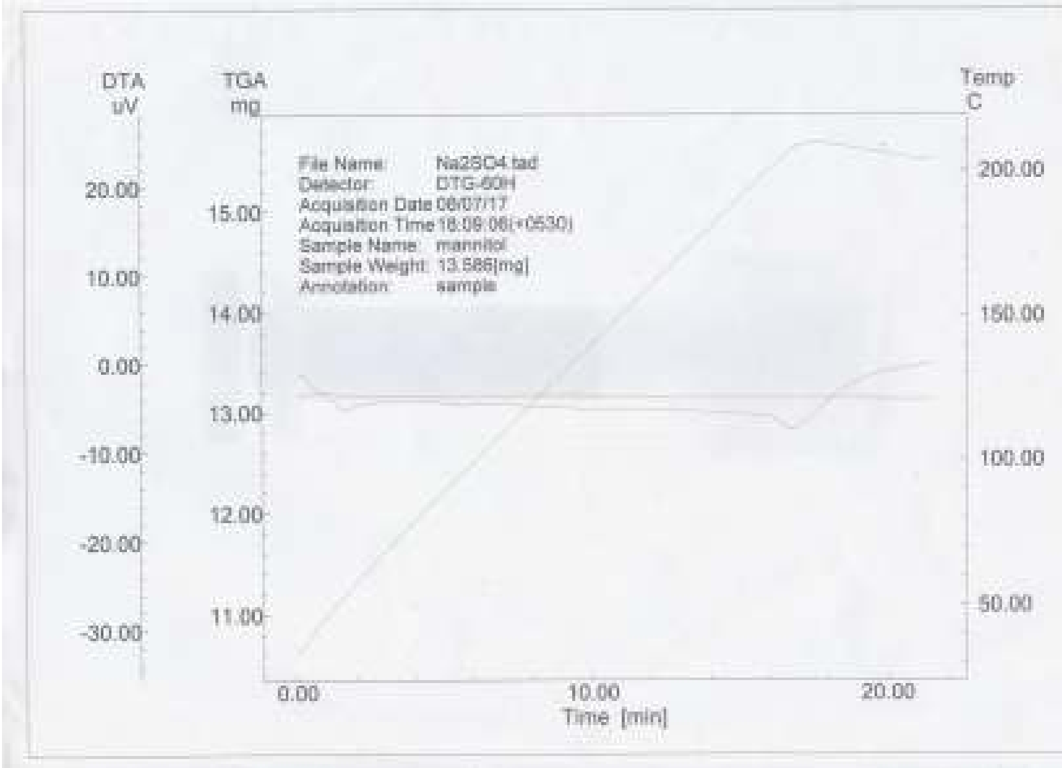


TGA and DTA plot spray dried $(NH_4)_2\ SO_4$
Figure 73

TGA and DTA plot spray dried NaCl
Figure 74



TGA and DTA plot spray dried Mannitol
Figure 75



TGA and DTA plot spray dried $Na_2 SO_4$
Figure 76